STATE OF CALIFORNIA
DEPARTMENT OF TRANSPORTATION
DIVISION OF CONSTRUCTION
OFFICE OF TRANSPORTATION LABORATORY

EVALUATION OF WEATHERING EFFECTS ON STRUCTURAL STEEL

Study Supervised by .... Eric F. Nordlin, P.E.
William F. Crozier, P.E.

Principal Investigator .... Franklin O. Reed, P.E.

Co-Principal Investigator ...... Charles B. Kendrick, P.E.

Advisor .... Philip Warriner, P.E.

G. L. RUSSELL, P.E.
Chief, Office of Transportation Laboratory

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16. ABSTRACT

The corrosion rates of ASTM A7, A242 Type 1, A588 Grades B, G and H, and A514 Grades D, E and F steels are compared after weathering 13 years in suburban and industrial environments with low rainfall and in a marine environment located, respectively, at Sacramento, Los Angeles and Point Reyes, California. Four types of specimens were prepared from each steel for each environment, namely; 1) plate with butt and surface welds, 2) plate with back to back angles tack welded to it, 3) plate with spaced angles welded to it, and 4) plate with an angle bolted to it.

The corrosion rate of the A7 steel in the low rainfall environments was 60 percent less than expected. The corrosion resistance of the A242 and A588 steel averaged, respectively, 1.4 $\pm$ 0.1, 1.1 $\pm$ 0.1 and 1.9 $\pm$ 0.3 times the A7 steel in the suburban, industrial and marine locations. Similar relative resistances of the A514 steels averaged, respectively, 1.6 $\pm$ 0.2, 1.1 $\pm$ 0.1 and 2.0 $\pm$ 0.4. The average corrosion rates of the A588, A242 and A514 steels in the marine enviroment were, respectively, 2.1 and 3.7 times greater than those in the industrial and suburban environments. Localized corrosion and pitting occurred unpredictably in the marine environment.

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Neither the State of California nor the United States Government endorse products or manufacturers. Trade or manufacturers' names appear herein only because they are considered essential to the object of this document.

CONVERSION FACTORS

English to Metric System (SI) of Measurement

Quantity	English unit	Multiply by	To get metric equivalent
Length	inches (in)or(")	25.40 .02540	millimetres (mmm) metres (m)
	feet (ft)or(')	.3048	metres (m)
	miles (mi)	1.609	kilometres (km)
Area	square inches (in^2)	6.432×10^{-4}	square metres (m^2)
	square feet (ft^2) acres	.09290 .4047	square metres (m^2) hectares (ha)
Volume	gallons (gal)	3.785	litres (l)
	cubic feet (ft^3)	.02832	cubic metres (m^3)
	cubic yards (yd^3)	.7646	cubic metres (m^3)
Volume/Time (Flow)	cubic feet per second (ft^3/s)	28.317	litres per second (l/s)
	gallons per minute (gal/min)	.06309	litres per second (l/s)
Mass	pounds (lb)	.4536	kilograms (kg)
Velocity	miles per hour (mph) feet per second (fps)	.4470 .3048	metres per second (m/s) metres per second (m/s)
Acceleration	feet per second squared (ft/s^2)	.3048	metres per second squared (m/s^2)
	acceleration due to force of gravity (G)	9.807	metres per second squared (m/s^2)
Weight Density	pounds per cubic (lb/ft^3)	16.02	kilograms per cubic metre (kg/m^3)
Force	pounds (lbs) kips (1000 lbs)	4.448 4448	newtons (N) newtons (N)
Thermal Energy	British thermal unit (BTU)	1055	joules (J)
Mechanical Energy	foot-pounds (ft-lb) foot-kips (ft-k)	1.356 1356	joules (J) joules (J)
Bending Moment or Torque	inch-pounds (ft-lbs) foot-pounds (ft-lbs)	.1130 1.356	newton-metres (Nm) newton-metres (Nm)
Pressure	pounds per square inch (psi)	6895	pascals (Pa)
	pounds per square foot (psf)	47.88	pascals (Pa)
Stress Intensity	kips per square inch square root inch (ksi $\sqrt{in}$)	1.0988	mega pascals $\sqrt{metre}$ (MPa $\sqrt{m}$)
	pounds per square inch square root inch (psi $\sqrt{in}$)	1.0988	kilo pascals $\sqrt{metre}$ (KPa $\sqrt{m}$)
Plane Angle	degrees (°)	0.0175	radians (rad)
Temperature	degrees fahrenheit (F)	$\frac{tF - 32}{1.8} = tC$	degrees celsius (°C)

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1. INTRODUCTION

History

Corrosion of steel structures has long been a problem to engineers in terms of costly initial protective coatings, maintenance of coatings, and repair or replacement of steel. Material shortages and environmental restrictions, along with inflated costs, have aggravated these problems. The steel industry, in response to these problems, has developed numerous "weathering steels" which are advertised to have four to six times the corrosion resistance of plain carbon steel and twice the corrosion resistance of carbon steel with copper in the unpainted condition. In addition, these steels possess higher yield and ultimate strengths which allow savings in materials and dead weight.

The mechanism of this increased corrosion resistance is the addition of small amounts of alloying metals which combine with the steel and corrosive agents to form a tight rust which protects and slows down the corrosion of the underlying metal.

Researchers have found, however, that rates of corrosion and corrosion patterns vary with atmospheric conditions, with the type and concentrations of pollutants, and with other factors as well. Michigan Department of Transportation, for example, has found that in sheltered areas with salt present and prolonged time of wetness, the corrosion process continued actively.(1)

Michigan Department of Transportation has approximately 500 bridges constructed from A588 weathering steel during the period 1965 through 1979 and is expecting to have to paint them at service lives of 10-20 years.(1) This in itself presents no difficulty but they are finding that the salt is very difficult, if not impossible, to remove from the pitted surface of the steel. The presence of salt due to its use in deicing and moisture seems to be the biggest cause of corrosion.

California Application

California, fortunately, does not have Michigan's problem of many unpainted steel bridges and heavy usage of deicing salts. Tax dollars might be saved, therefore, by using weathering steel or a similarly corrosion resistant structural steel unpainted in areas where corrosion will form a stable impervious coating or patina that protects the surface. The corrosion rates of these steels are, however, difficult to predict because many factors affect these rates. There are, moreover, limited data available to indicate how corrosion rates would vary for different climatic and geographic locations in California.

Purposes and Objectives

The purpose of this project, therefore, was to evaluate the corrosion resistance of weathering steels and other similarly alloyed structural steels at suburban, industrial, and marine locations in California by means of a series of observations and measurements defined in the following project objectives:

1. To measure overall corrosion rates and assess general oxidation patterns observed on a series of corrosion test specimens from samples of weathering and similar structural steels exposed for a number of years at each of the three corrosion test sites.

2. To assess the corrosion buildup, if any, on the faying surfaces of bolted and of welded joints.

3. To assess the color, buildup, and pitting of the corrosion on the various filler metals in the weld joints.

4. To assess any unusual localized corrosion or pitting on any of the corrosion test specimens.

Steel Types Tested

One carbon, five weathering and three quenched and tempered structural steels were selected for this corrosion study. These steels are identified in Table I.

TABLE I

ASTM Designation and Grade or Type	Manufacturer or Source	Proprietary Name
A7	CalTrn Stock(CHC)	--
A242 Type 1	Beth. Steel	Mayari R
A242 Type 1	U.S. Steel	Cor-Ten A
A588 Grade B	U.S. Steel	Cor-Ten B
A588 Grade G	Armco Steel	Hi Strength A
A588 Grade H	Kaiser Steel	Kaisaloy 50 CR
A514 Grade D	Armco Steel	SSS100
A514 Grade E	Armco Steel	SSS100A
A514 Grade F	U.S. Steel	T-1

Specimen Types and Preparation

A sample from each of the steels which were to be tested was made into four types of corrosion test specimens. Type 1 was a 12"x12" square flat plate containing two butt welds and two or four surface welds machined flush over one-half their lengths. These Type 1 specimens are illustrated in Figures 2a through 10b. Types 2 and 3 specimens were 6"x12" rectangular flat plates with two 3" lengths of 3x3 angles of the same steel variously attached to them. Type 2 had the two angles intermittently welded "back to back" to the plate to form an inverted T with unsealed faying surfaces between the legs of the joined angles and the plate. Type 3 had the two angles separated. Each angle was fillet welded to the plate all around the faying angle leg to seal faying surfaces. The Type 4 specimen was a 6"x12" rectangular flat plate with a 6" length of 3x3 angle bolted to it so that the faying surfaces were not sealed. Specimen Types 2, 3 and 4 are illustrated in Appendix B.

The plates and angles used to make the specimens were sandblasted to a white metal finish before being joined with welds or fasteners. The thickness of each plate was measured to the nearest mil at 12 to 14 points around its edges after it had been sandblasted. The points at which the measurements were made are located by distance from the end and the side of the plate. These distances were recorded so that thicknesses could be remeasured at the same points after the steels had weathered. The weight of each assembled specimen was recorded to the nearest gram before it was exposed at any of the test sites.

Corrosion Test Sites

A total of 108 corrosion test specimens were fabricated for this project. There were 4 specimens from each of 9 steel samples exposed on weathering racks at each of three types of corrosion test sites in California. The site selected for the marine atmosphere corrosion tests was the ASTM test rack located 1300 feet from the ocean on the Point Reyes peninsula 35 miles northwest of San Francisco. The site selected for the industrial atmosphere corrosion tests was the city of Commerce, an incorporated industrial area 6 miles southeast of the Los Angeles Civic Center. The site selected for the suburban atmosphere corrosion tests was Caltrans Transportation Laboratory on the southeastern outskirts of Sacramento, a city with no heavy industry and located in the middle of a farming area about 100 miles from the ocean.

Test Procedures

Test specimens were photographed on the racks at intervals during the first 2 years of exposure. After 13 years of exposure, the specimens at each site were photographed, removed from the racks, individually encased in plastic bags, and returned to the Transportation Laboratory for analysis. There they were weighed, measured, photographed again, chemically analyzed for unusual corrosion products and for sulfur and chlorine in these products, chemically stripped of corrosion and reweighed. This report covers the information gathered from these test procedures.

2. CONCLUSIONS

The corrosion rates of weathering and of quenched and tempered structural steels determined by this project are in reasonable agreement with the corrosion rates for similar steels reported by C. P. Larrabee and S. K. Coburn(10). The corrosion rates determined for carbon steel in urban and industrial environments was much less than that reported for similar environments by Larrabee and Coburn. These lower corrosion rates were attributed to the reduced rainfall at the urban and industrial test sites used in the California tests. These comparisons are shown in Table D in Appendix A wherein Larrabee's and Coburn's data have been interpolated to provide 13-year penetration values.

The corrosivities of the three test environments (based on penetration equivalent to the averaged corrosion of the weathering and the quenched and tempered steels) vary from 0.09 mils/year for the low rainfall urban environment to 0.16 mils/year for the low rainfall industrial environment to 0.33 mils/year for the marine environment. Thus, corrosion in the marine environment was 2.1 times that in the industrial environment and 3.7 times that in the urban environment, and corrosion in the industrial environment was 1.8 times that in the urban environment. On this basis, one can assign relative corrosivities of 1 to nonindustrial locations in California desert and valley regions, 1.8 to industrial locations in these desert and valley regions, and 3.7 to all regions within 10 miles of the Pacific Ocean or any saline embayment contiguous with the ocean.

These penetration rates derived from racked corrosion specimens may not be valid for sheltered horizontal and vertical surfaces which can collect debris and moisture without ever being washed clean. An examination of such surfaces on the unpainted weathering steel in the Antioch Bridge indicates that the penetration rate on such surfaces may be as high as 2.5 mils/year.

Unpainted weathering steels and unpainted quenched and tempered steels corrode at the same rate in the same environment.

Weathering and quenched and tempered structural steels pit and corrode too irregularly and too deeply in a marine environment to be safe for long term use without a protective paint system. Pitting occurred on the faying surfaces of eight of the nine bolted corrosion specimens tested in the marine environment.

The long term corrosion rates of weathering and of quenched and tempered structural steels do not appear to vary with rainfall within the limits found in California.

The long term corrosion rates of carbon steels appear to be directly proportional to rainfall as well as to the quantity of chlorides and sulfides present in the atmosphere.

Comparisons of the corrosion rates of carbon steels with those of weathering and those of quenched and tempered structural steels are invalid without an adjustment to account for the influence of rainfall on the corrosion rate of carbon steel. The corrosion resistance of the tested weathering steels averaged, respectively, 1.4 $\pm$ 0.1 times, 1.1 ± 0.1 times and 1.9 ± 0.3 times that of the tested carbon steel at the urban and industrial locations of low rainfall and at the marine location. Similar comparisons for the tested quenched and tempered steels averaged 1.6 ± 0.2 times, 1.1 ± 0.1 times, and 2.0 ± 0.4 times.

No weathering or quenched and tempered steel tested displayed a corrosion resistance more than 2.52 times greater than that of carbon steel in the corresponding test.

Weldments do not increase the corrosion rates or cause localized corrosion of butt welded plates or angles welded to plates. Weldments do not cause great differences in color of weathered specimens.

3. RECOMMENDATIONS

Weathering steels should be painted in marine and industrial environments with relative corrosivities of 1.8 times greater than that incurred in a rural or urban environment. It may be possible to use weathering steel in the unpainted condition in inland suburban locations but site conditions should be investigated before hand. Tension members subject to cyclic loading should be protected against pitting.

4. IMPLEMENTATION

Relative corrosion rates of five weathering steels and three quenched and tempered versus carbon steel at three environmentally different locations in California determined by this project should be considered by designers who are planning to use unpainted weathering steel in a steel structure.

The photographic record of the weathered appearance of the nine steels used in this project are available to designers who are concerned with designing aesthetically pleasing structures.

5. TECHNICAL DISCUSSION

5.1 Specimen Preparation

In order to retain a permanent identification of all specimens, a coded system of notches was developed. Specimens can be readily identified with this system by referring to Figure 1 and as follows:

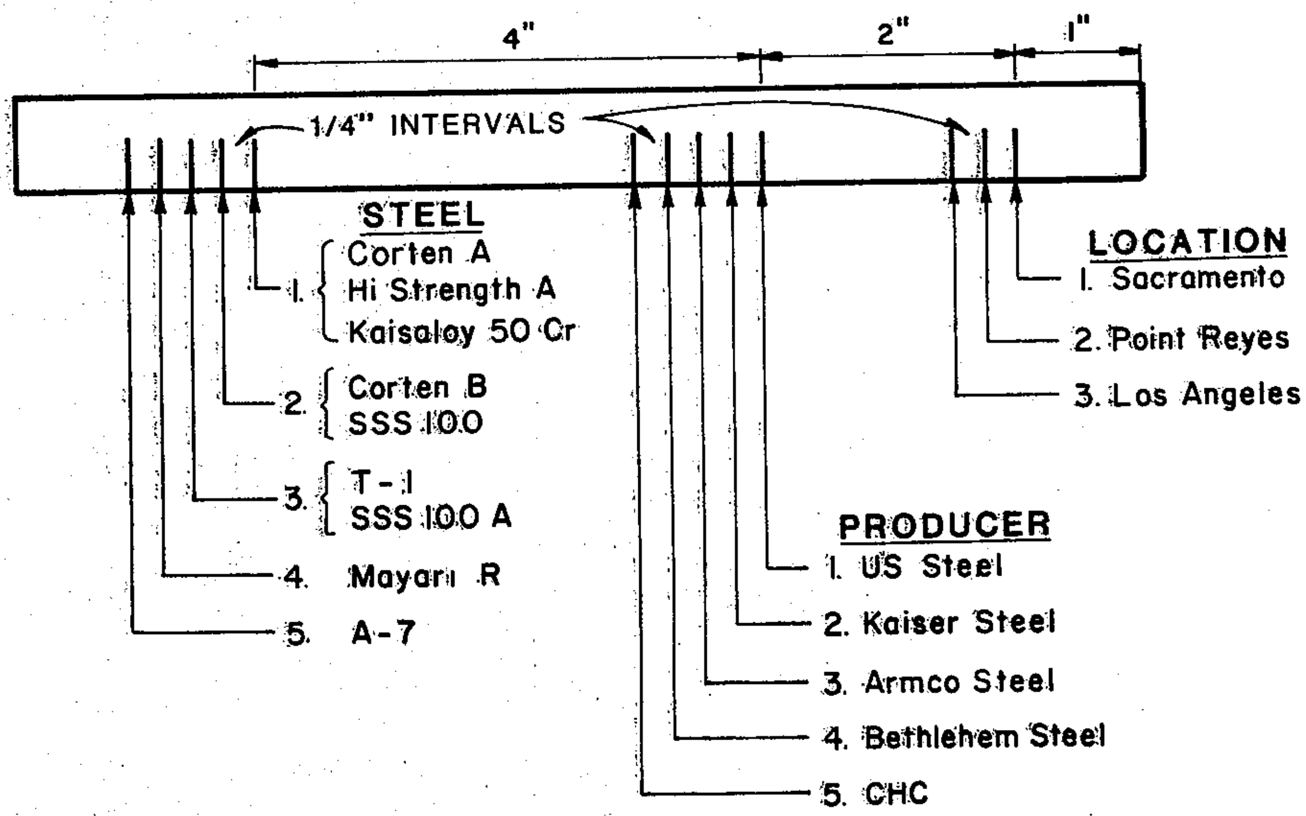
The first notch measured from the right end indicates location as follows:

1" from end Sacramento, 1-1/4" from end Point Reyes, 1-1/2" from end Los Angeles. The three locations are coded with the digits 1 through 3, respectively.

The second notch indicates the producer and is coded 1 through 5. The third notch indicates the steel grade and is coded 1 through 5. Finally, the configuration type butt welded plate, welded spaced angles, etc., is coded 1 through 4. Using this system, and if the 1st notch measures 1", the second 3", the third 7" and the configuration is butt welded plate, the coded number would be 1111. This would indicate (going from right to left) that the location is Sacramento, the producer is U.S. Steel, and the grade of steel is Cor-Ten A (since that is the only steel grade in group 1 produced by U.S. Steel) and the configuration is butt welded plate.

The butt welded plates were welded by lab personnel with a selection of electrodes for comparison of corrosivity and color. Part of the reinforcement was ground flush so that

EDGE VIEW PLATE



TYPE

1. Butt - Welded Plate.
2. Intermittenly Welded Angles.
3. All Welded Angle.
4. Mechanically Attached Angle.

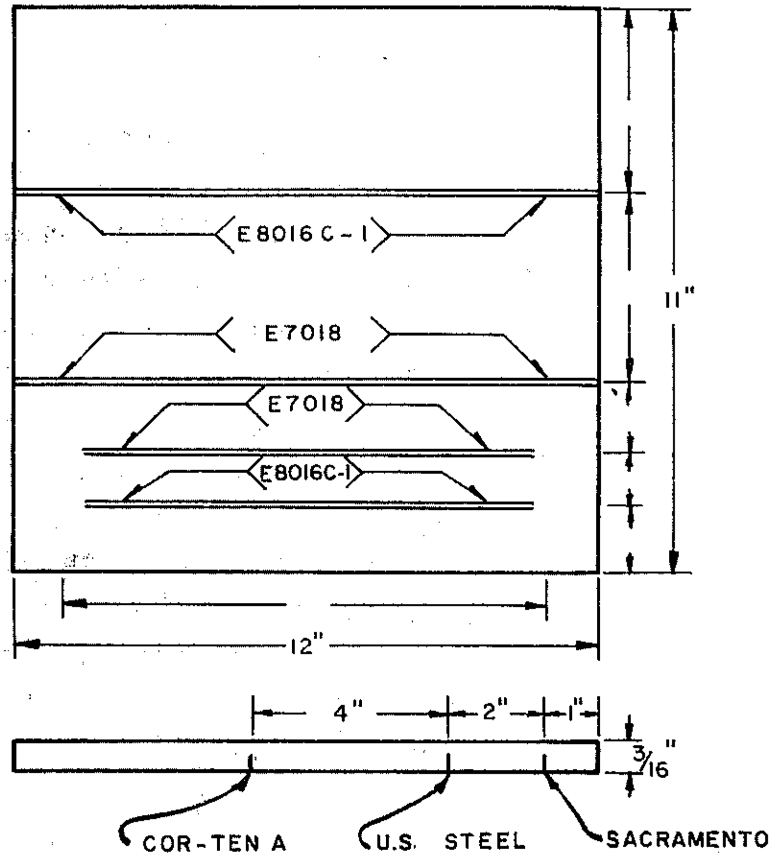
SPECIMEN IDENTIFICATION

FIGURE 1

color and corrosion patterns for this condition and also for the condition of undisturbed reinforcement could be evaluated. The electrode designations used on each steel grade for the butt-welded plates, along with a photograph of the Sacramento specimens with corrosion products intact, are presented in Figures 2a through 10a. Similarly, photographs of butt-welded plates from the Los Angeles and Point Reyes sites can be seen in Figures 2b through 10b.

The plates and angles used for fabricating the intermittently welded butted angles and the all welded spaced angles were of the same grade of steel in each configuration. The electrodes used for each grade of steel were the same as the electrodes used for each grade of steel used in the butt-welded plates. Similarly, the angles and plates used in the mechanically attached specimens were of similar chemical composition but the hardware varied in composition as listed in Table A, Appendix A. Chemistries of the nine grades of steel and their ASTM designations at the time of placement at the three sites and the ASTM designations that they fit currently are presented in Table B, Appendix A. The bolted connections in the mechanically attached specimens were torqued to values also listed in Table A.

After sandblasting and assembling, the specimens were weighed to the nearest gram and the plates were measured with a micrometer to the nearest mil at 12 to 14 points around the periphery located by coordinate measurement. The specimens were then transported to the three sites and placed on racks specially prepared for them.


E8016C-1
E7018
E7018
E8016C-1
11"
12"
4"
2"
1"
3/16"
COR-TEN A
U.S. STEEL
SACRAMENTO

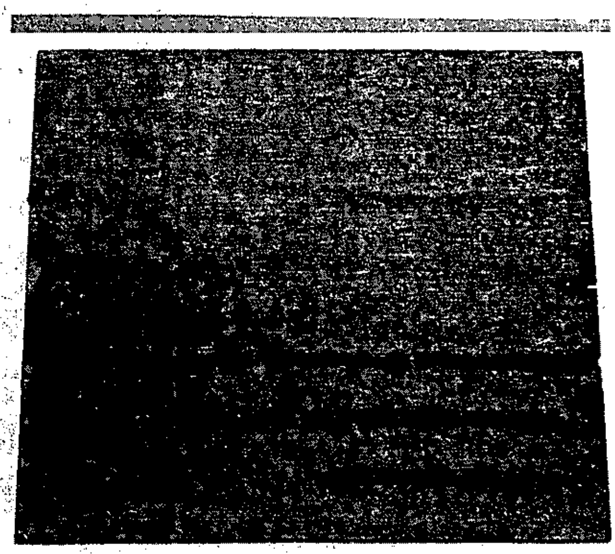
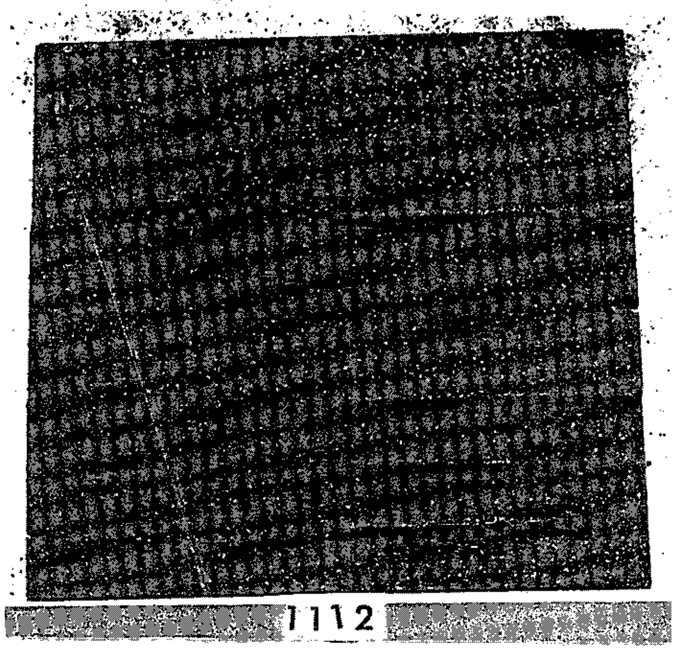
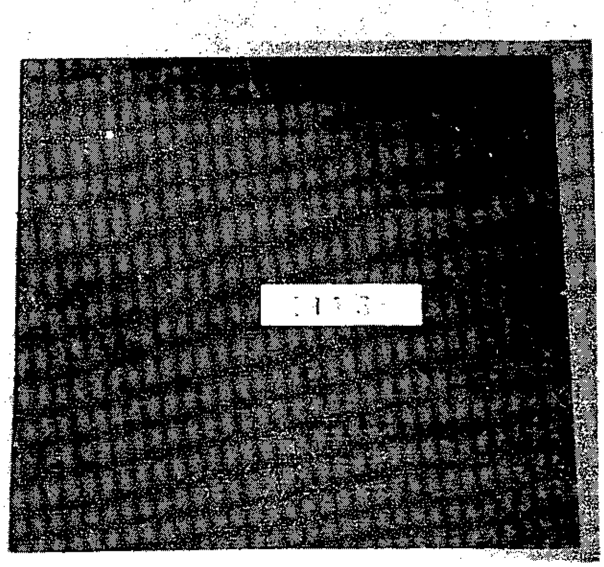


FIGURE 2a

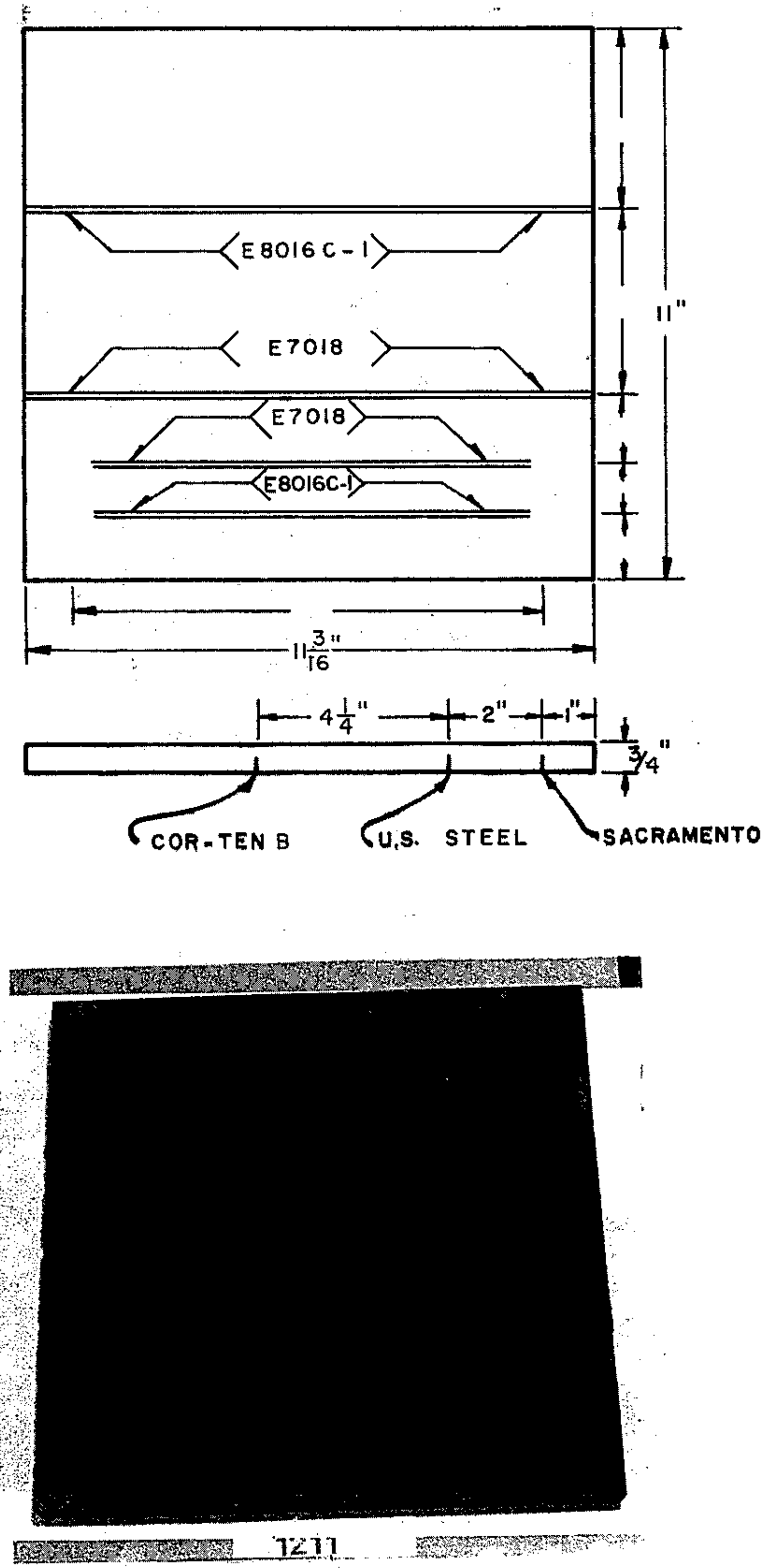


COR-TEN A U.S. STEEL PT REYES



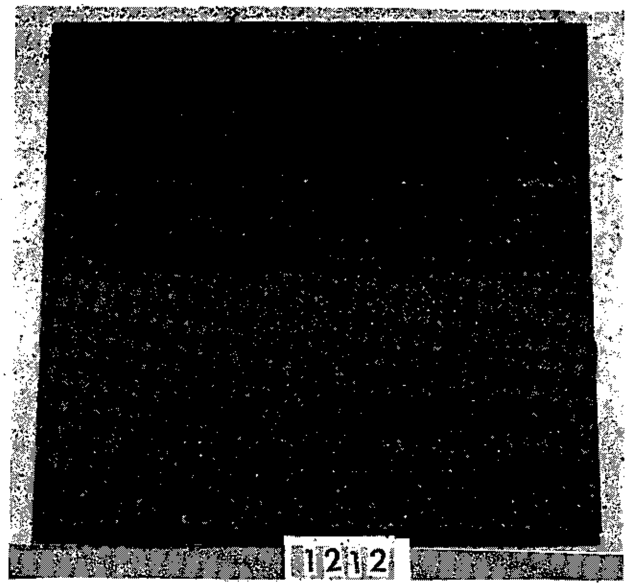
COR-TEN A U.S. STEEL LOS ANGELES

Figure 2b

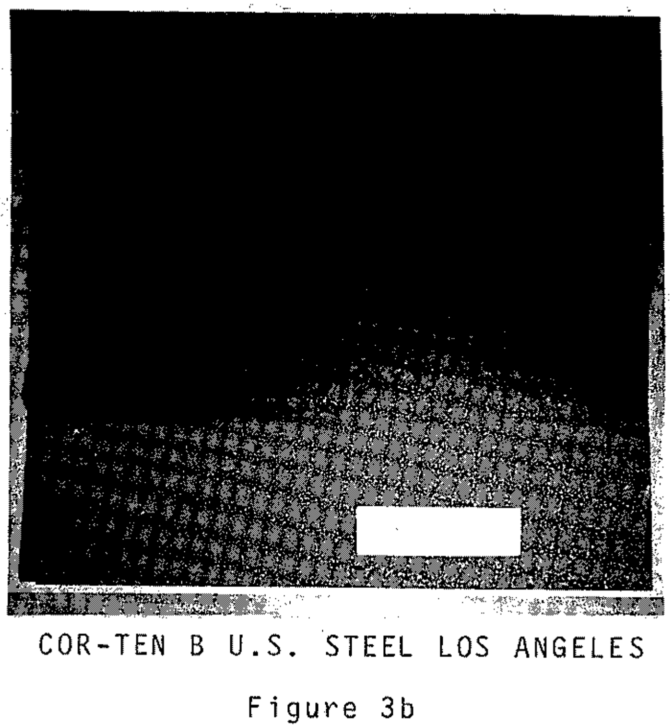


E8016C-1
E7018
E7018
E8016C-1
11"
11 3/16"
4 1/4"
2"
1"
3/4"
COR-TEN B
U.S. STEEL
SACRAMENTO
1211

FIGURE 3a

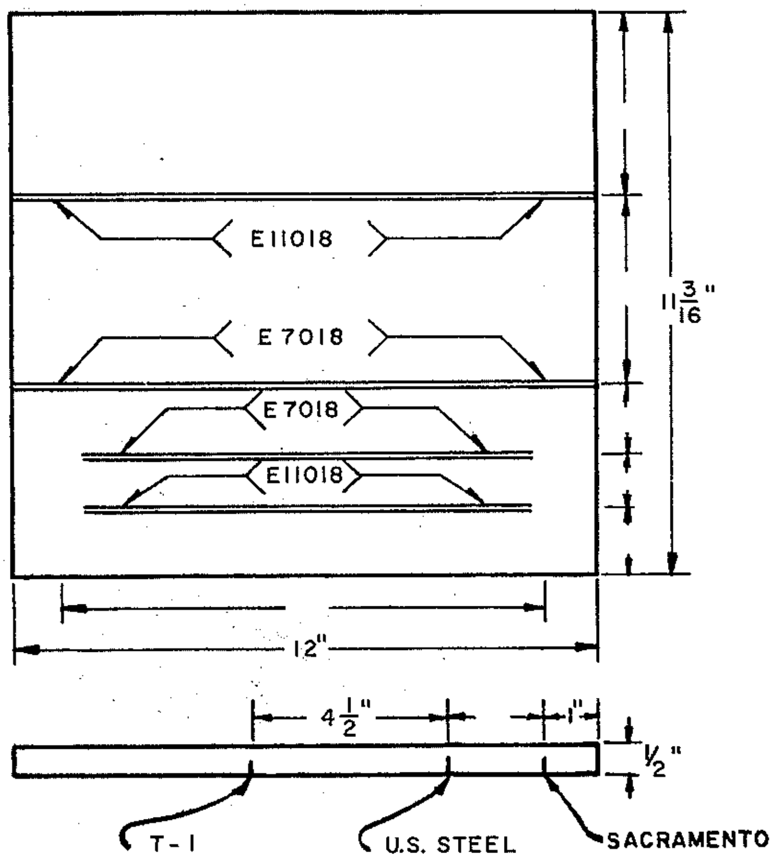


COR-TEN B U.S. STEEL PT REYES



COR-TEN B U.S. STEEL LOS ANGELES

Figure 3b


E11018
E7018
E7018
E11018
11 3/16"
12"
4 1/2"
1"
1/2"
T-1
U.S. STEEL
SACRAMENTO

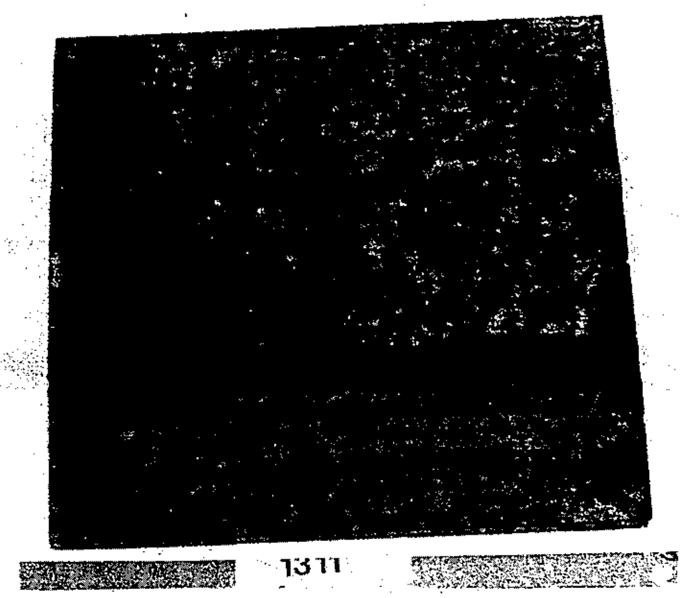
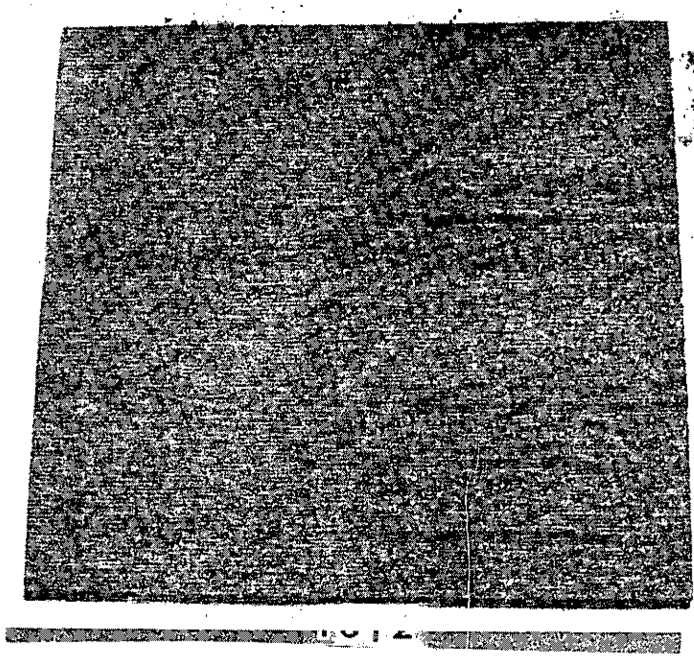
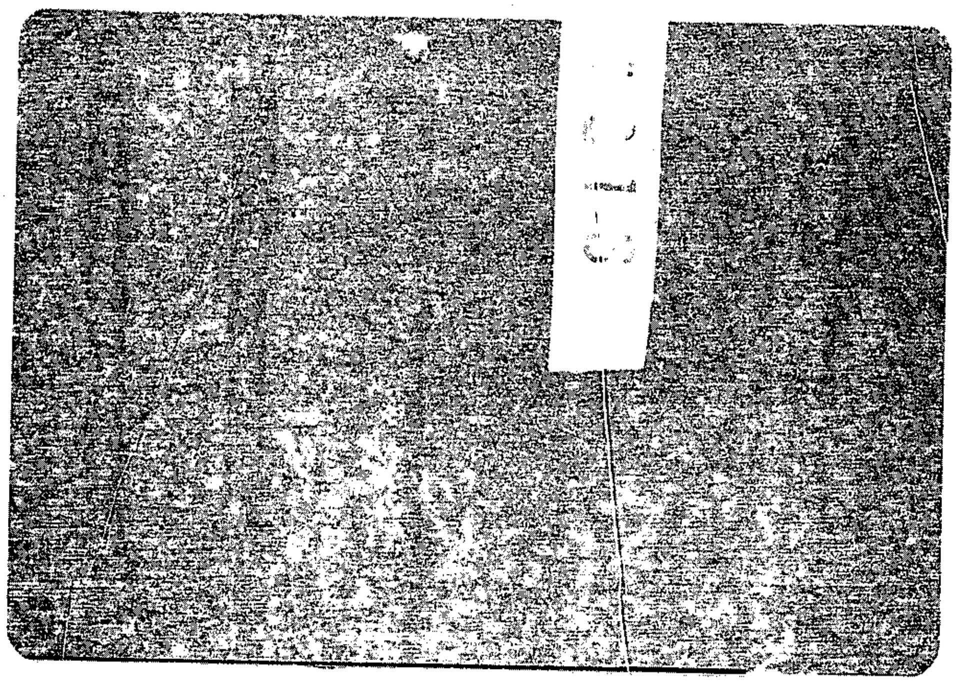

1311

FIGURE 4a



T-1 U.S. STEEL PT REYES



T-1 U.S. STEEL LOS ANGELES

Figure 4b

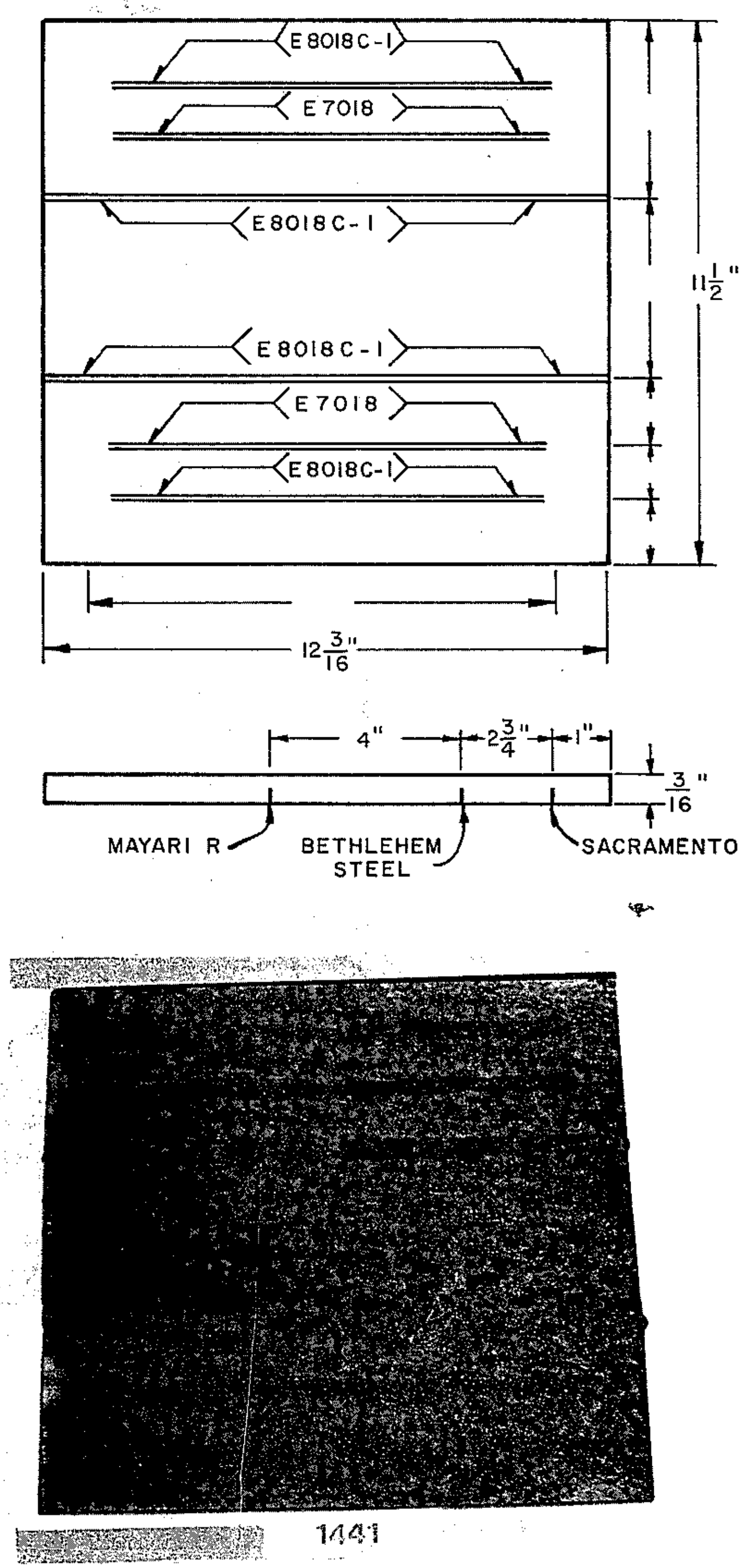
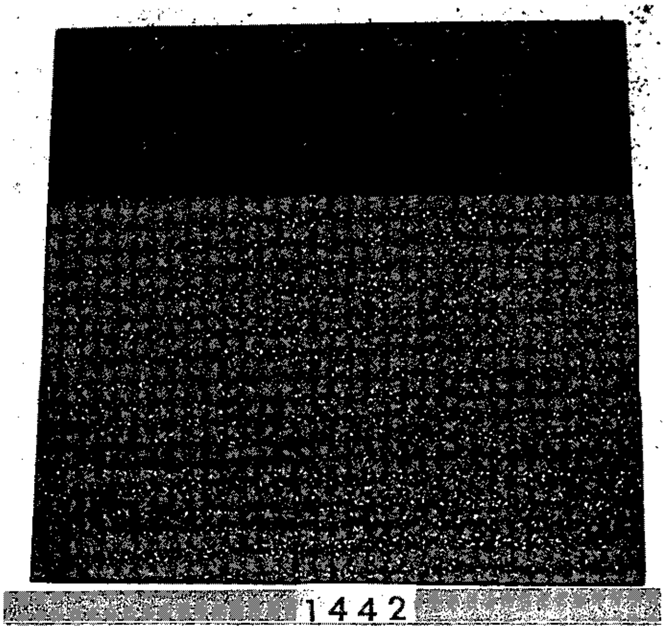
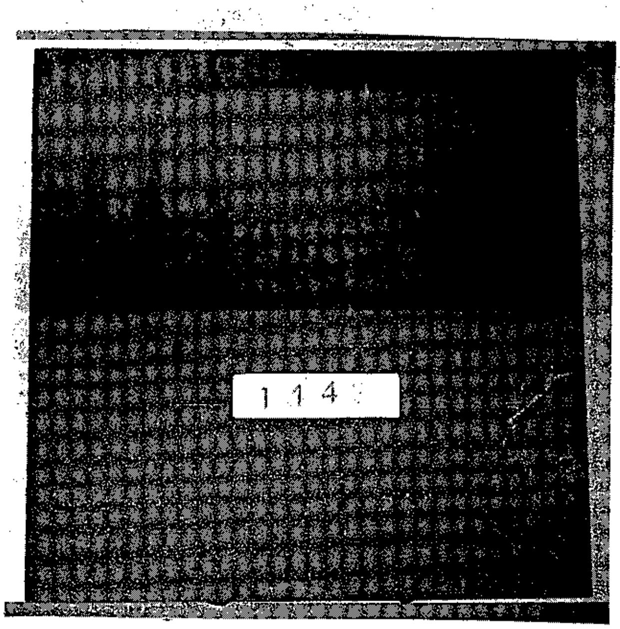

E8018C-1
E7018
E8018C-1
E8018C-1
E7018
E8018C-1
$11\frac{1}{2}$"
$12\frac{3}{16}$"
4"
$2\frac{3}{4}$"
1"
$\frac{3}{16}$"
MAYARI R
BETHLEHEM STEEL
SACRAMENTO
1441

FIGURE 5a



MAYARI R BETHLEHEM STEEL PT REYES



MAYARI R BETHLEHEM STEEL LOS ANGELES

Figure 5b

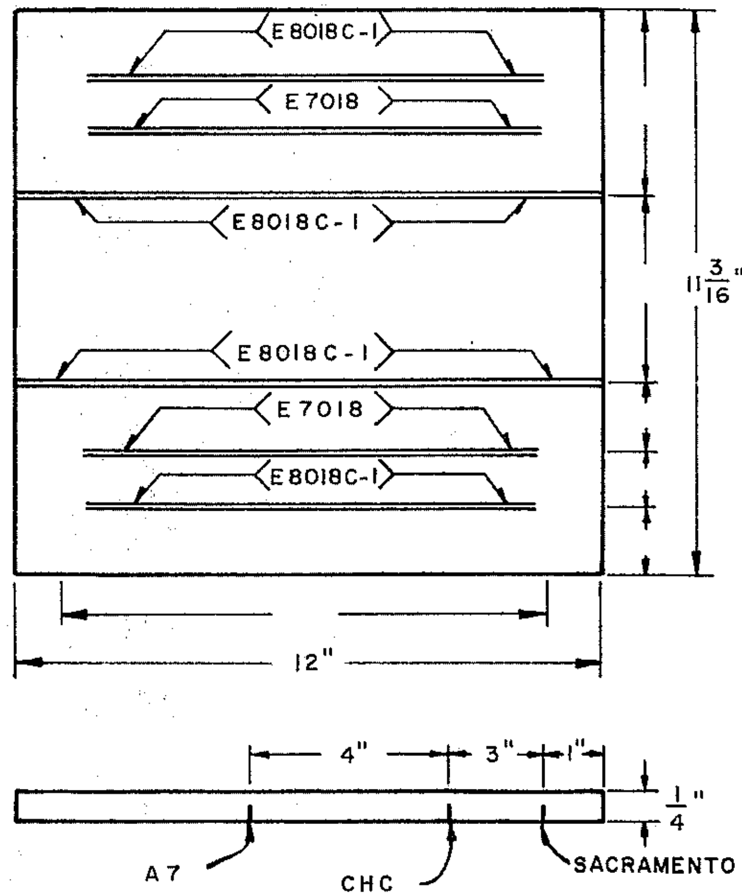
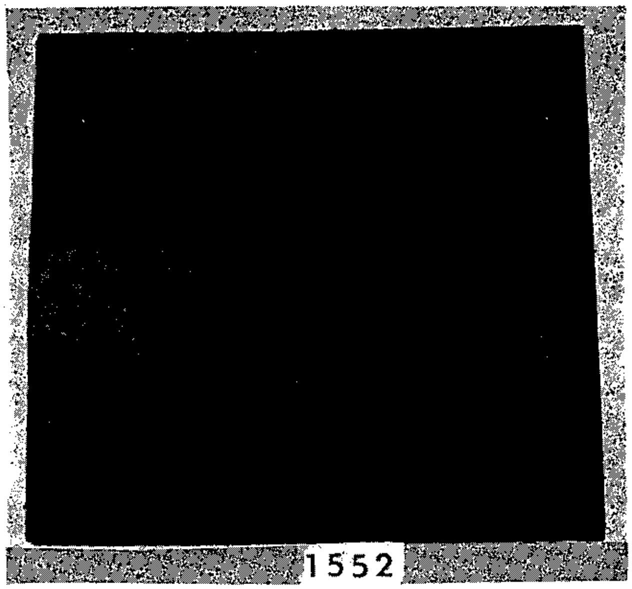
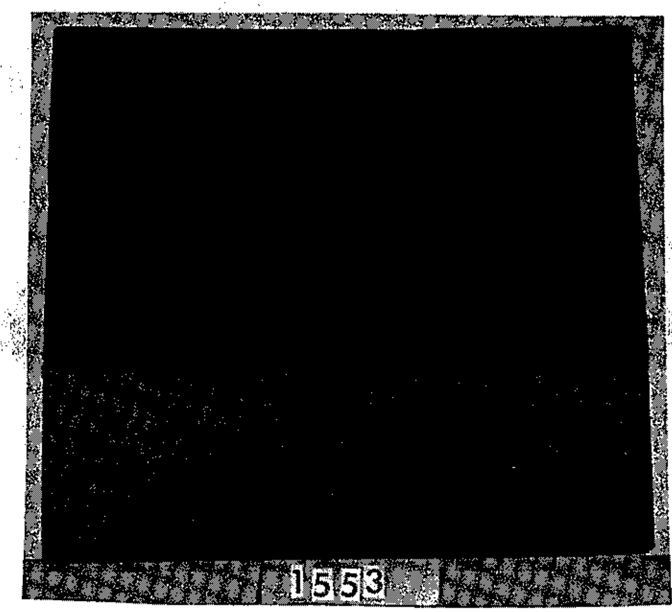

E8018C-1
E7018
E8018C-1
E8018C-1
E7018
E8018C-1
11 3/16"
12"
4"
3"
1"
1/4"
A7
CHC
SACRAMENTO

FIGURE 6a

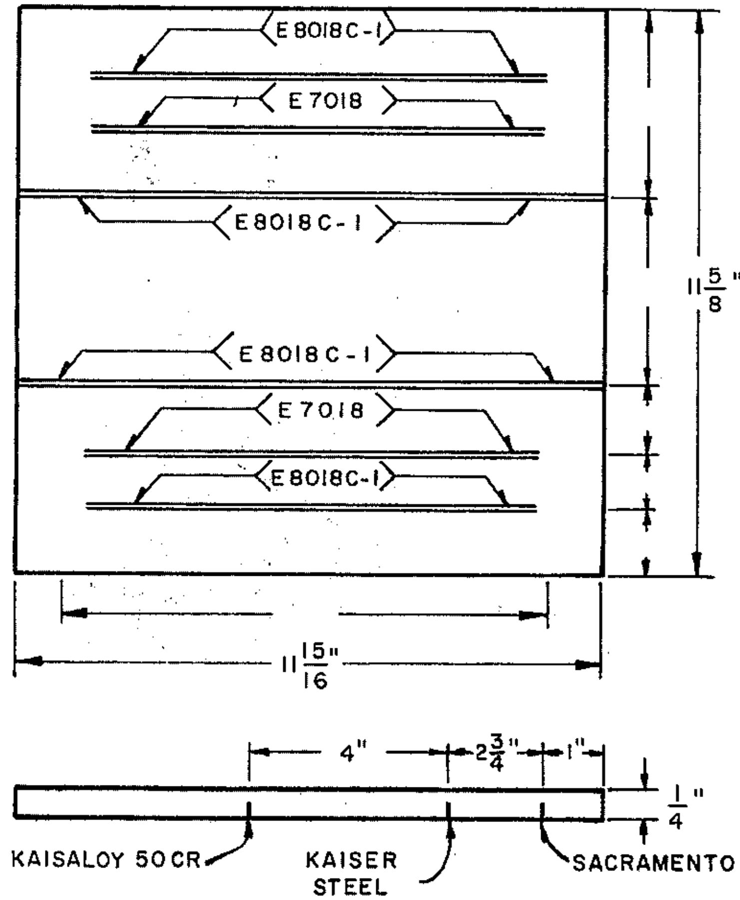


A7 CHC PT REYES



A7 CHC LOS ANGELES

Figure 6b


E8018C-1
E7018
E8018C-1
E8018C-1
E7018
E8018C-1
11 5/8"
11 15/16"
4"
2 3/4"
1"
1/4"
KAISALOY 50CR
KAISER STEEL
SACRAMENTO

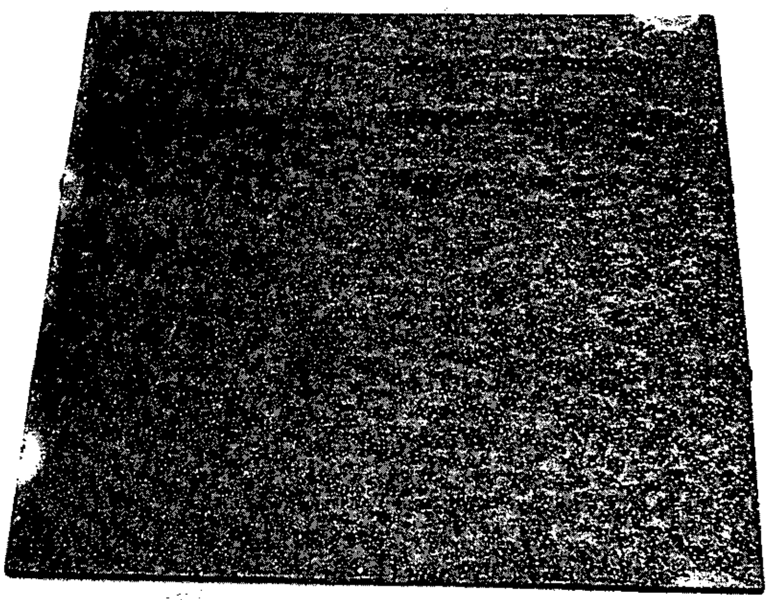
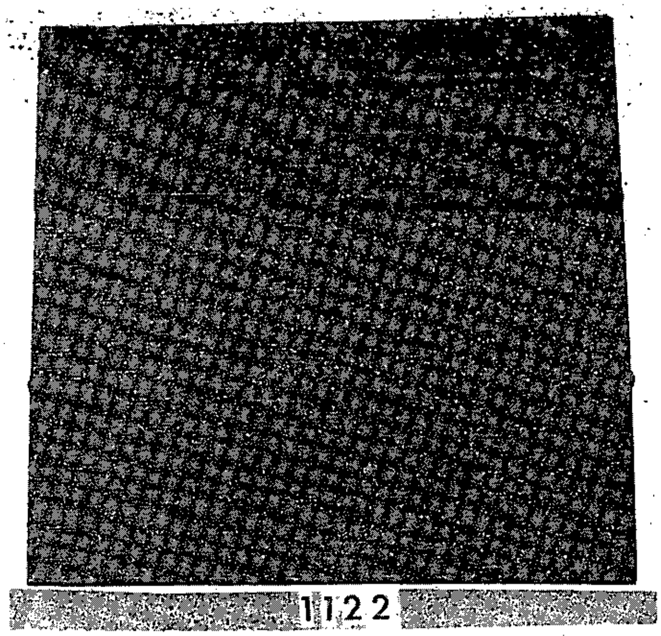
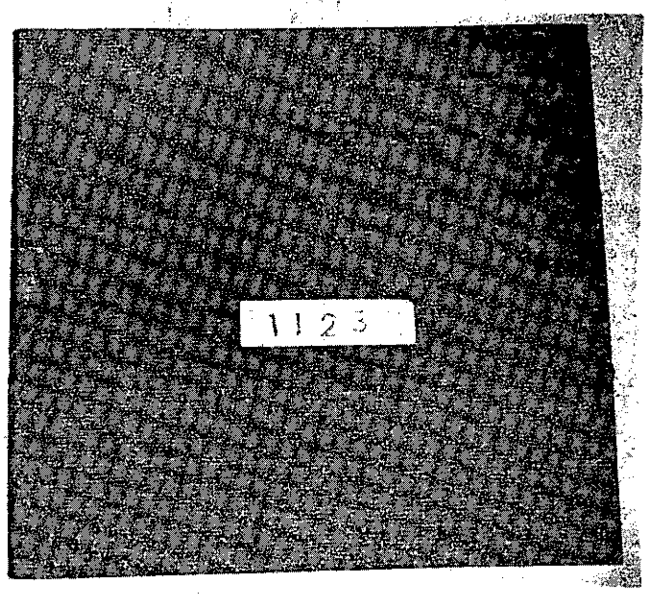


FIGURE 7a



KAISALOY 50 CR KAISER STEEL PT REYES



KAISALOY 50 CR KAISER STEEL LOS ANGELES

Figure 7b

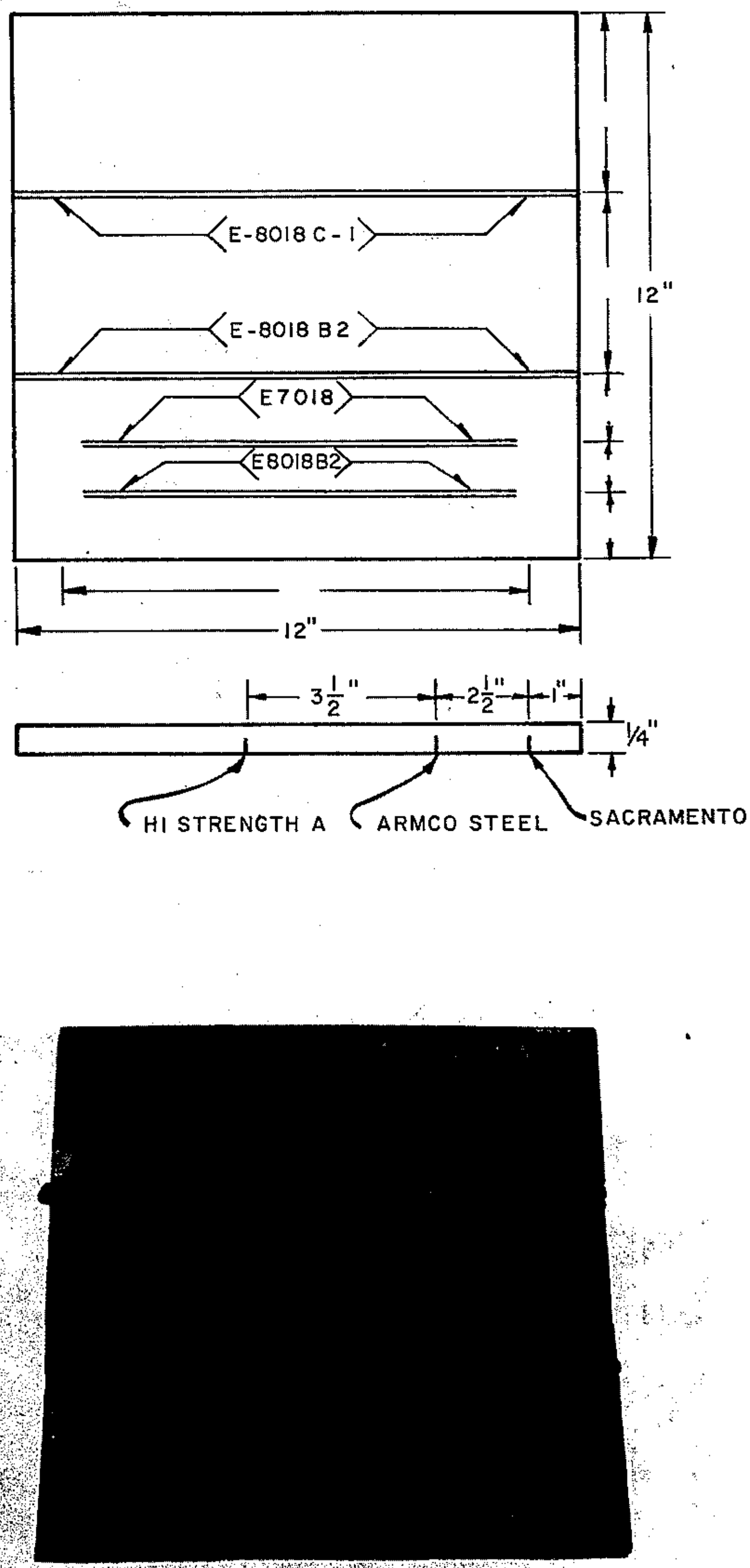
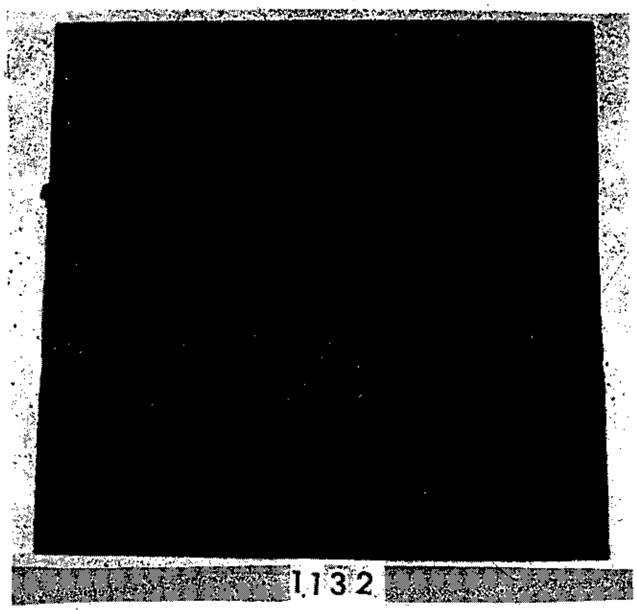
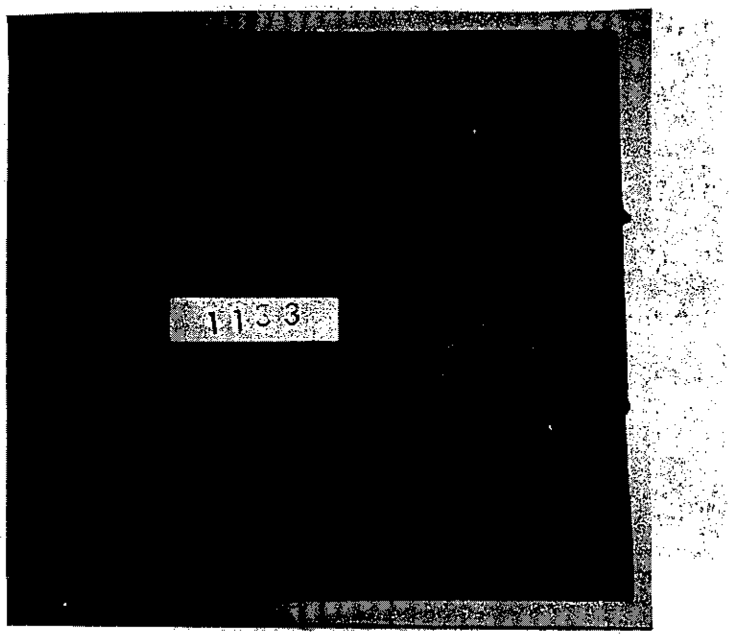

E-8018 C-1
E-8018 B2
E7018
E8018B2
12"
12"
3 1/2"
2 1/2"
1"
1/4"
HI STRENGTH A
ARMCO STEEL
SACRAMENTO

FIGURE 8a

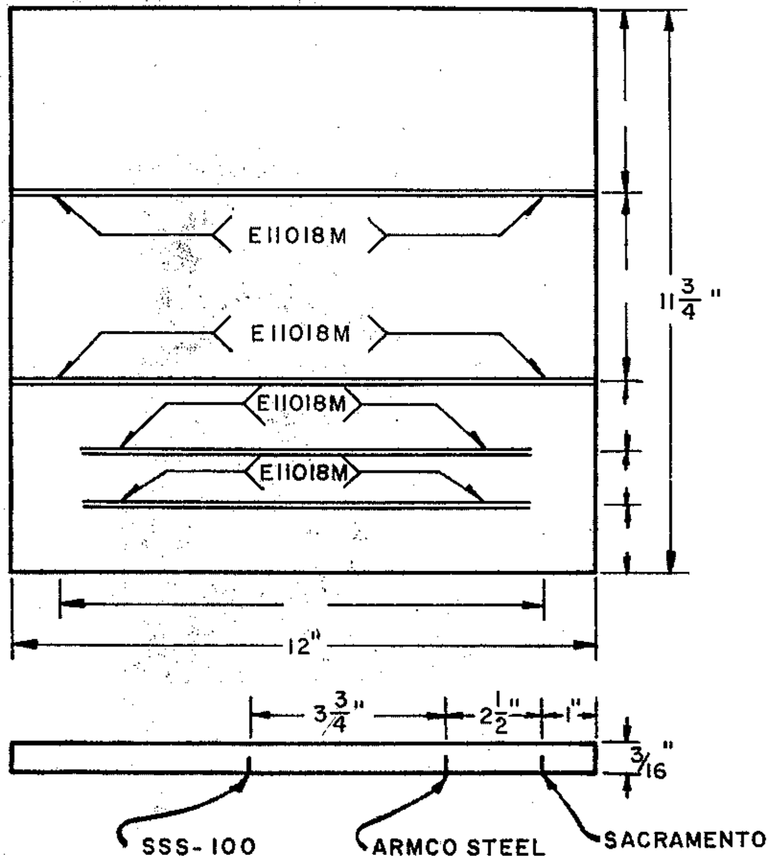


HI-STRENGTH A ARMCO STEEL PT REYES



HI-STRENGTH A ARMCO STEEL LOS ANGELES

Figure 8b


E11018M
E11018M
E11018M
E11018M
11 3/4"
12"
3 3/4"
2 1/2"
1"
3/16"
SSS-100
ARMCO STEEL
SACRAMENTO

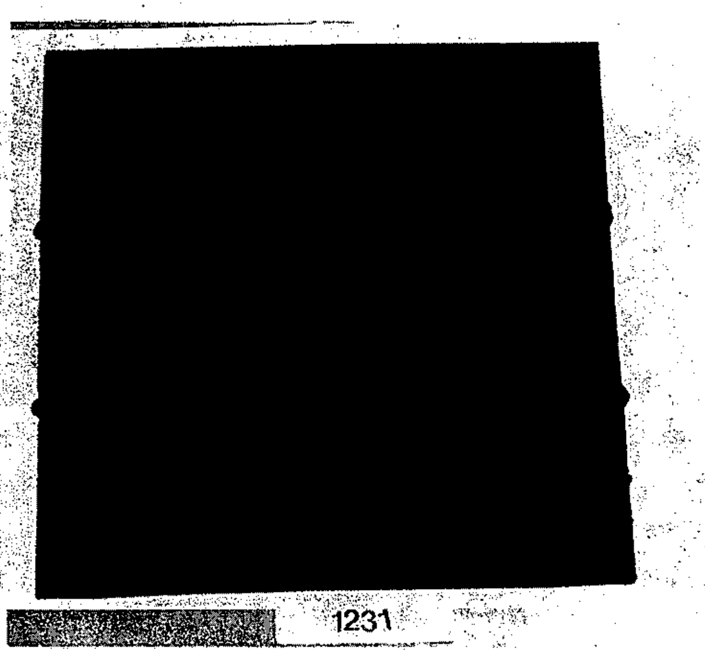
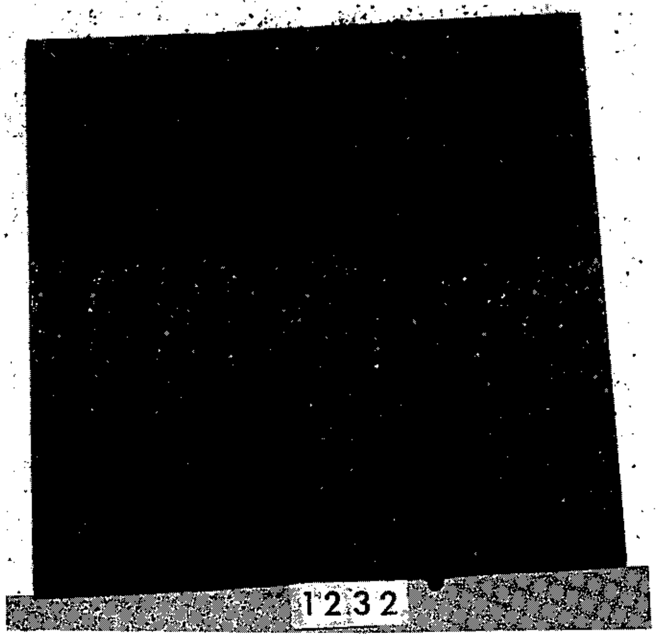
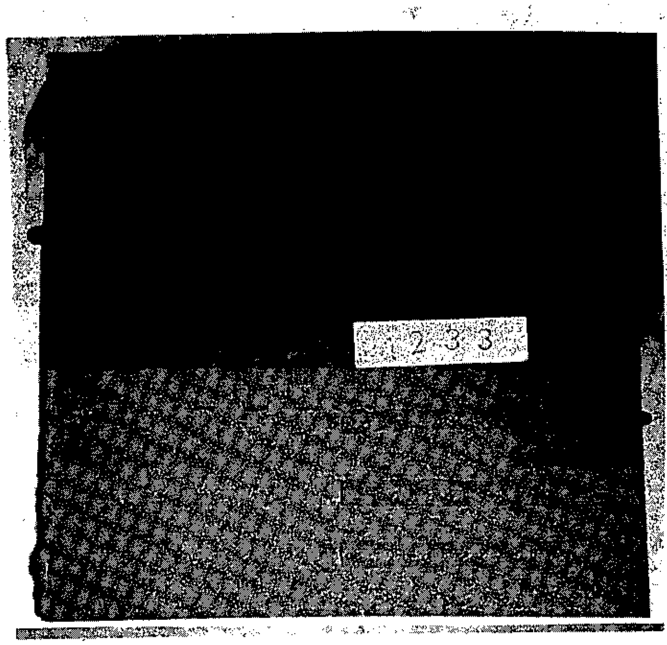

1231

FIGURE 9a

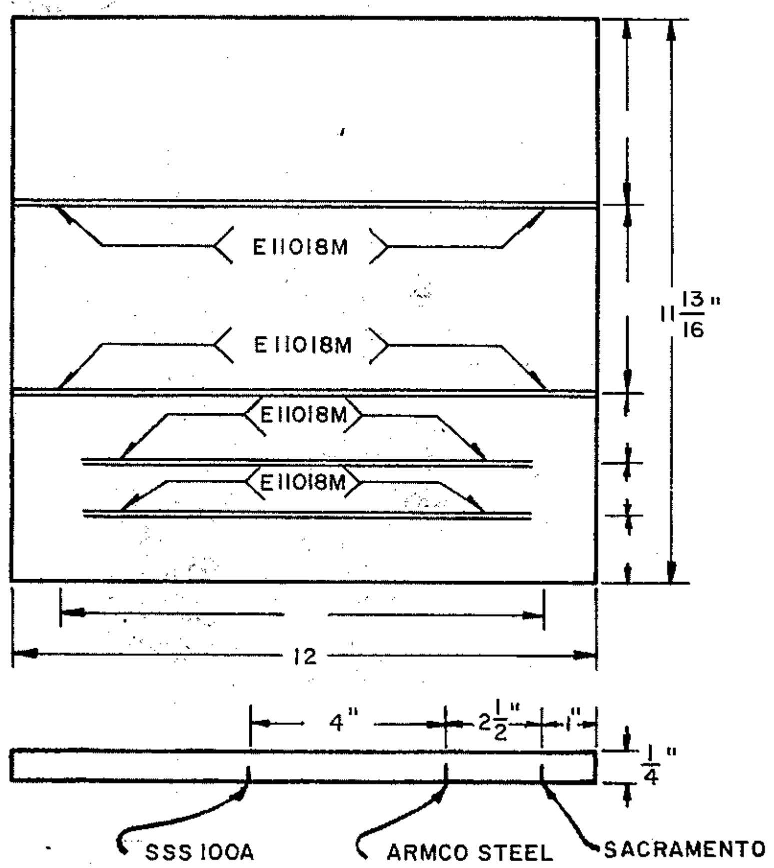


SSS-100 ARMCO STEEL PT REYES



SSS-100 ARMCO STEEL LOS ANGELES

Figure 9b


E11018M
E11018M
E11018M
E11018M
11 13/16"
12
4"
2 1/2"
1"
1/4"
SSS 100A
ARMCO STEEL
SACRAMENTO

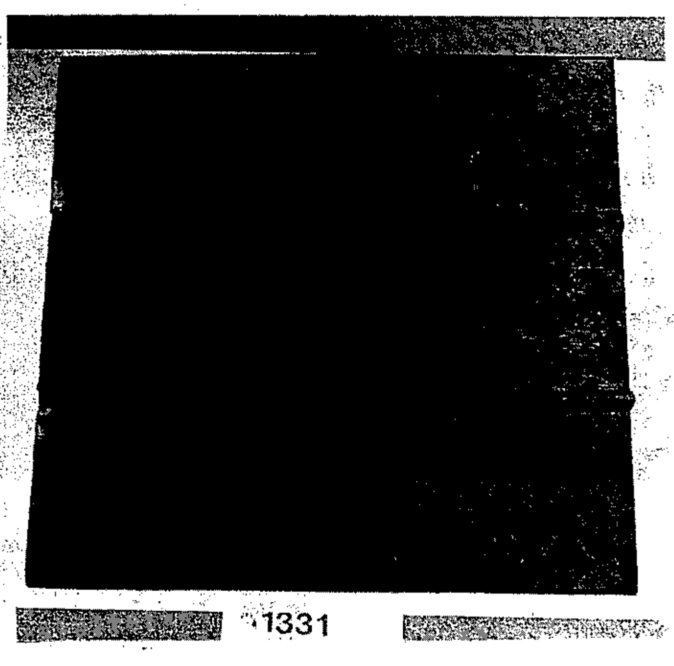
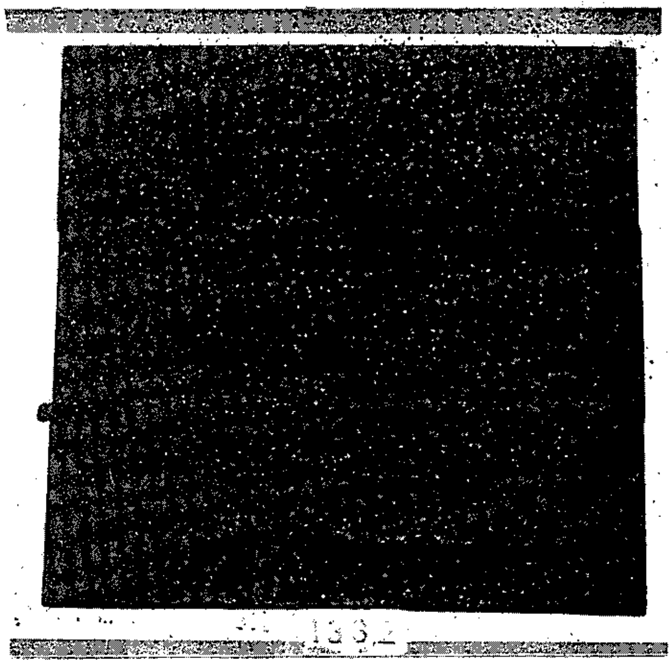
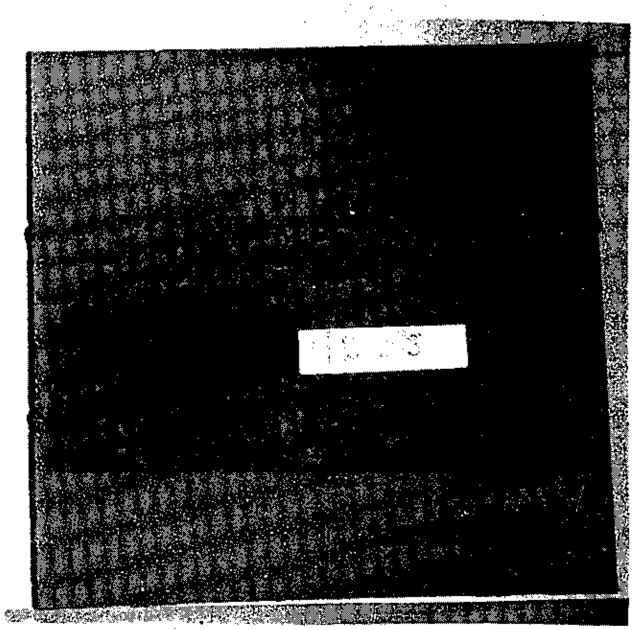

1331

FIGURE 10a



SSS 100 A ARMCO STEEL PT REYES



SSS 100 A ARMCO STEEL LOS ANGELES

Figure 10b

5.2 Site Description

The three sites selected to represent inland suburban, temperate coastal, and urban semi-industrial were, respectively, Sacramento, Point Reyes, and Los Angeles.

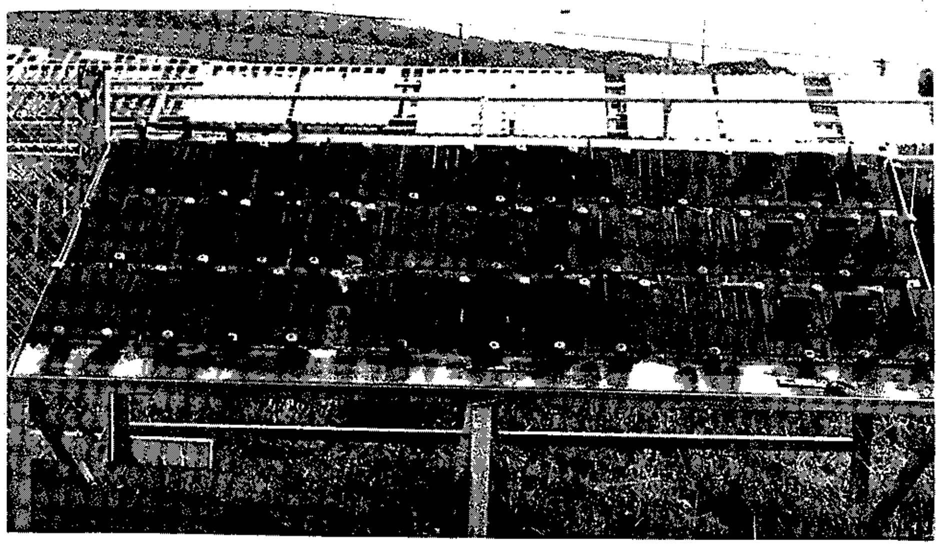
In Sacramento, the weathering rack was placed on top of what is now the main building of the Transportation Laboratory located on Folsom Boulevard between 59th and 65th Streets. This is about two miles southeast of the center of Sacramento. The rack was inclined 30° from the horizontal and faced south.

The Point Reyes site is located on the ASTM corrosion test site on the Point Reyes peninsula 1/4 mile from the ocean. The rack was inclined 30° from the horizontal and faced west.

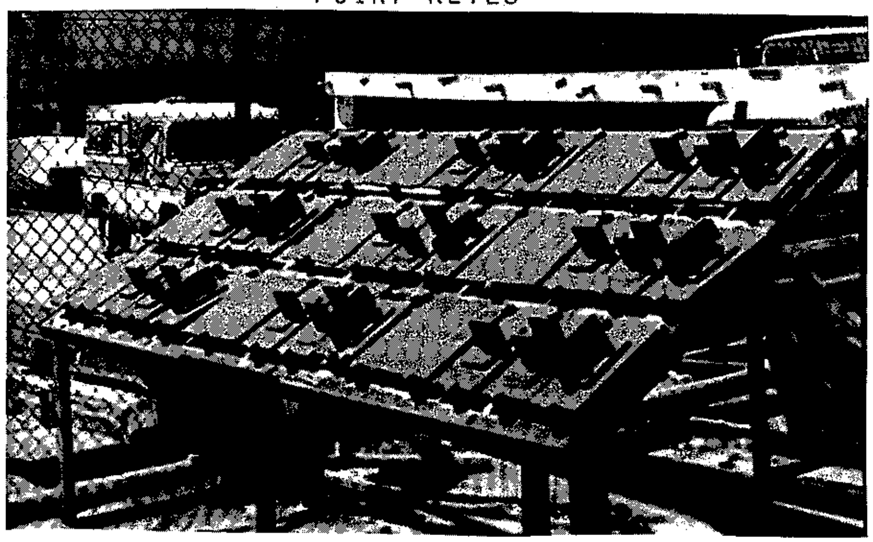
In Los Angeles, the weathering rack was placed at ground level at a California Department of Transportation Maintenance Station close to the Santa Ana Freeway (Interstate 5) in the City of Commerce which is a few miles southeast of the center of Los Angeles. This rack was inclined at 30° to the horizontal and faced east.

The specimens were held in place with ceramic insulators and spaced so that material washed from one would not contaminate another as can be viewed in Figure 11 which shows the specimens in place on the weathering racks at approximately 13 years.

SACRAMENTO



POINT REYES



LOS ANGELES

Figure 11

5.3 Specimen Removal

After photographing, the specimens were carefully removed from the racks and placed in plastic bags so that they would not be marred and also so that the loose corrosion products would be saved for possible analysis. In the Sacramento Transportation Laboratory, the specimens were weighed to the nearest gram with the corrosion products intact and the thickness measurements were made at the same points around the periphery of the plates where they were measured originally. At this time the specimens were examined for localized corrosion, swelling or prying action between the faying surfaces, and unusual color differences. Estimates were made of the relative roughnesses of the surfaces of the specimens at this time.

Individual color prints and color slides were made of all specimens.

5.4 Cleaning and Measurement

The specimens were dipped in Clark's Solution as per ASTM G-1 and brushed with a soft bristle brush until the corrosion products were removed(9). After the specimens were removed from the Clark's Solution they were washed with water and then rinsed with ethanol and allowed to air dry.

After cleaning, the specimens were again measured at the original points to the nearest mil and weighed to the nearest gram for thickness loss and weight loss determination. The original, intermediate, and final weighings and average thickness measurements along with the differences in average thicknesses and calculated weight losses in grams/-square decimeter are presented in Table C, Appendix A. Areas used in the determination of weight loss per unit area are total surface areas exposed. That is, edges, angle faces, faces of bolts and so on are all included.

Faying surface area is, however, not included.

5.5 Color Appraisal

As can be seen in the photographs of the individual specimens in Appendix B and Figures 2a,b through 10a,b, the color varies considerably between sites but is fairly uniform within the site. The color of the Sacramento specimens was generally a dark brown with reddish to purple mottling. The Point Reyes specimens tended to be a brighter orange color. The Los Angeles specimens were a dull plain brown color. The ground weld areas and untouched weld reinforcement colors were not appreciably different from the other surface colors.

5.6 Surface Roughness

The surface roughness of the Sacramento specimens with corrosion products intact, as estimated with a comparitor, ranged from 125 to 250 micro inches on the fully exposed surfaces and 250 to 500 plus micro inches on the under surfaces with no major deviations between the individual specimens. The surface roughness of the Point Reyes specimens varied between 250 and 500 micro inches on the fully exposed surfaces and 500 plus micro inches on the undersides of the specimens. The Los Angeles specimens varied in roughness on the fully exposed surfaces in the 125 to 250 micro inch range and 250 to 500 micro inches on the undersides. These roughness comparisons do not include localized severe corrosion which will be dealt with on an individual basis.

5.7 Data Analysis

5.7.1 Weight Loss

The weight loss per unit area data proved to be more consistant than the thickness measurements. This data can be found in Table C, Appendix A.

The average thickness measurements can also be found in this table but due to their inconsistancy, more attention was given to the weight loss per unit area.

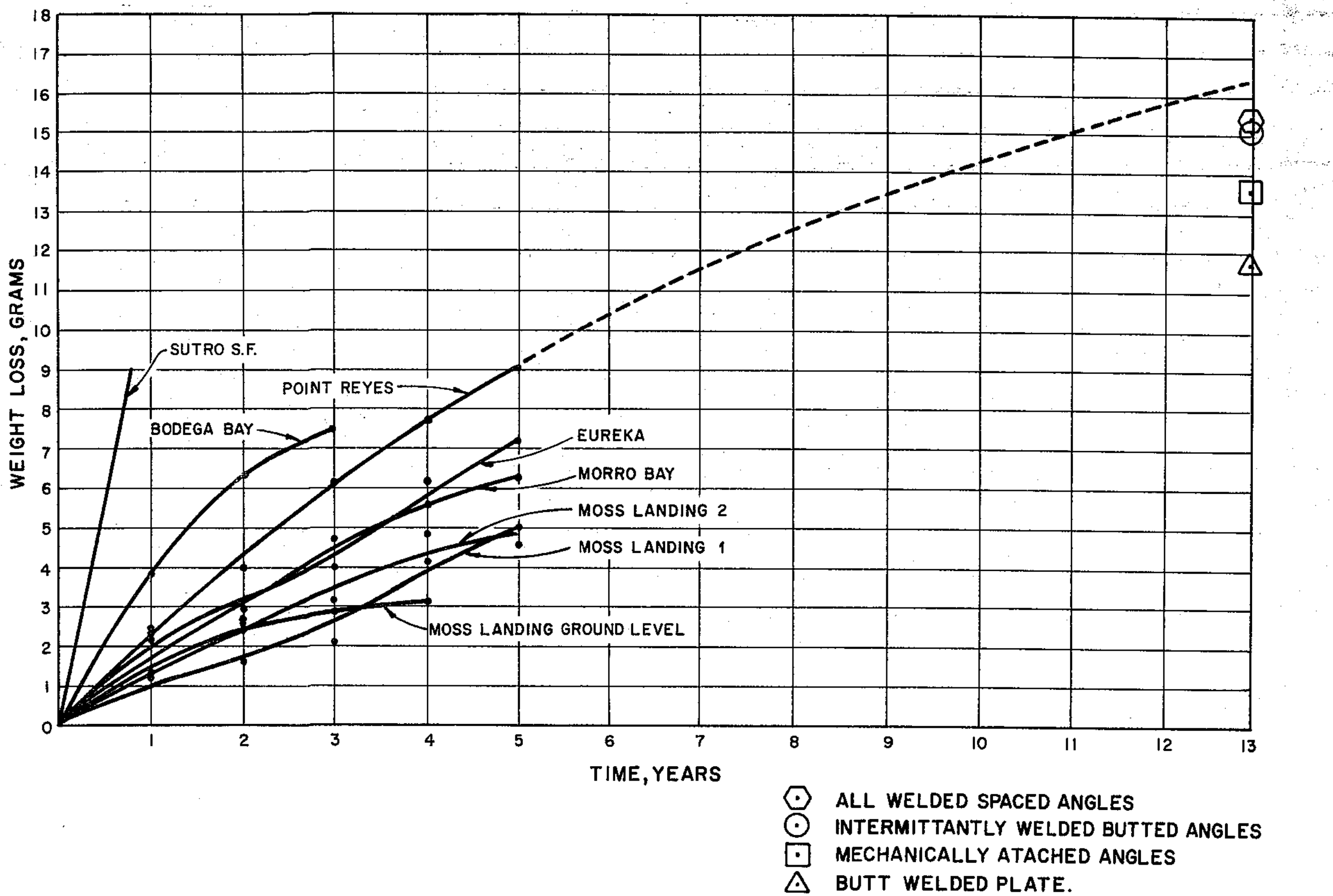
Comparisons of relative corrosion resistance were made for each location on the basis of weight loss per unit area. These comparisons, which are listed in Table D, are made relative to the weight loss per unit area of the ASTM A7 specimens. The comparison was made separately for each configuration at each location. It can be readily seen that none of the steels have a relative corrosion resistance greater than 2.52 except some in the butted angle group.

The accuracy of the data in the butted angle group is suspect because of the unknown amount of corrosion between the angles. The data in Table D for the Hi-Strength A, SSS-100,and SSS 100A butt-welded plates at the Los Angeles site are also suspect because of nonagreement with the results from the other configurations.

The CHC material was all plain carbon steel meeting the chemical and physical requirements of ASTM A7 except the angles used in the all welded spaced angles and the mechanically attached angles which contained enough copper to meet the requirements of copper steel. This accounts for the low weight loss per unit area of these two groups as compared to the butt-welded plates.

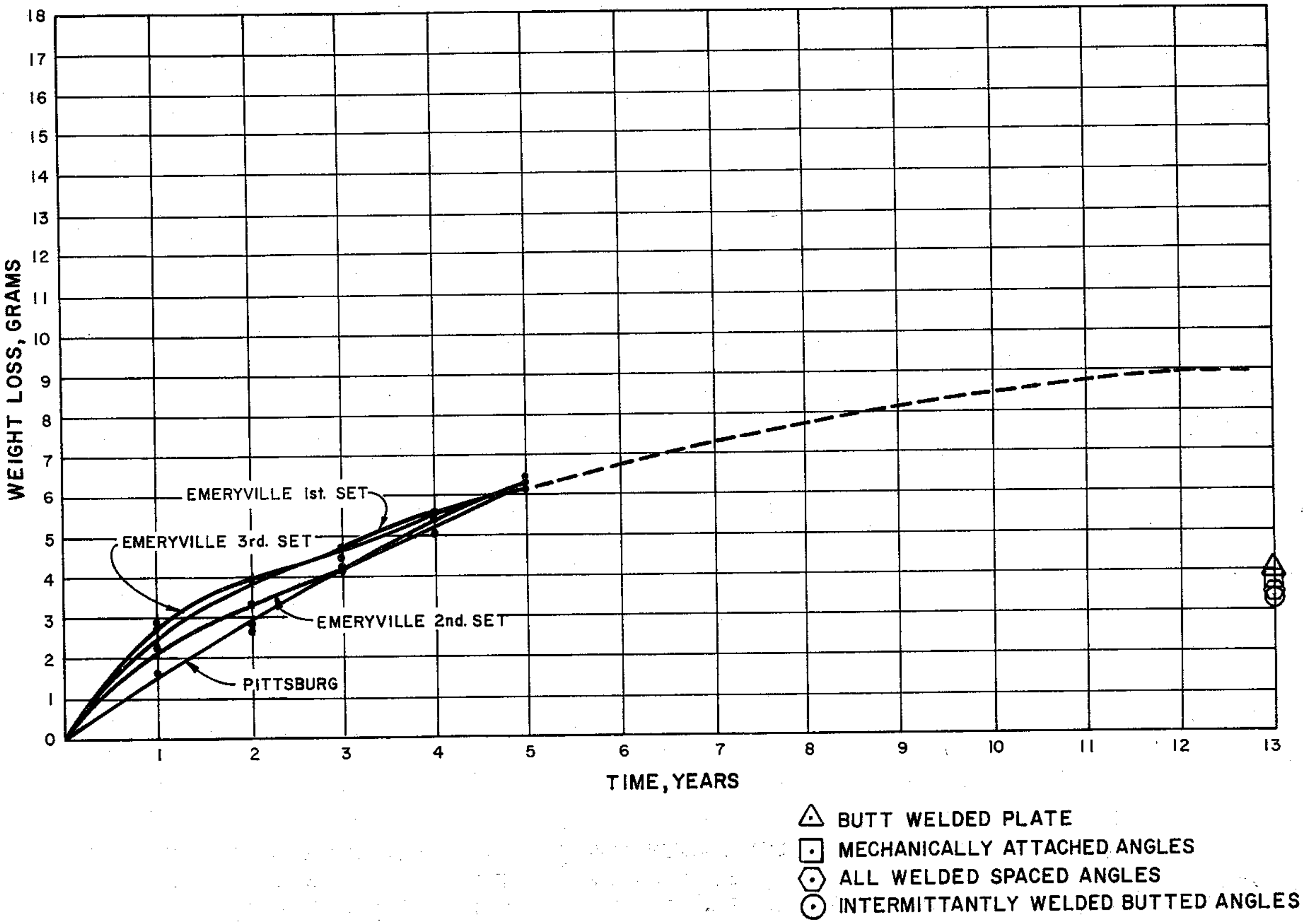
One of the nuts used with the Cor-Ten A mechanically attached angle configuration placed at Point Reyes was almost 60% corroded away (see specimen 4112, Figure 15a, in Appendix B) and the surface of the angle underneath the nut was dished out. This appeared to be some sort of battery action and when a side of the nut was polished, etched, and observed under a microscope, the nut turned out to be extremely low in carbon. The carbon content turned out to be less than 0.1% which is roughly the carbon content of ingot iron. The weight loss due to the low carbon nut and the reaction with the low alloy angle contributed substantially to the weight loss per unit area of this specimen (4112).

The weight loss per unit area after 13 years of the Point Reyes and Los Angeles specimens is compared to results of Thomas and Alderson(2) in Figures 12 and 13. Their graphs for marine and industrial environments are projected to 13 years so that a comparison of weight loss per unit area may be made. Table C gives weight loss in grams per square decimeter and the graphs by Thomas and Alderson give only total weight loss in grams but they list the dimensions of their specimens so that the area may be calculated. Also, their specimens are "MT 1010" steel which has a different chemistry from the A7 mild steel used in this project. However, it can be seen that the results at Point Reyes



TRANSLAB DATA POINTS SUPERIMPOSED ON A GRAPH OF ATMOSPHERIC CORROSION OF STEELS AS A FUNCTION OF TIME (COSTAL AREA) FROM THOMAS AND ALDERSON

FIGURE 12



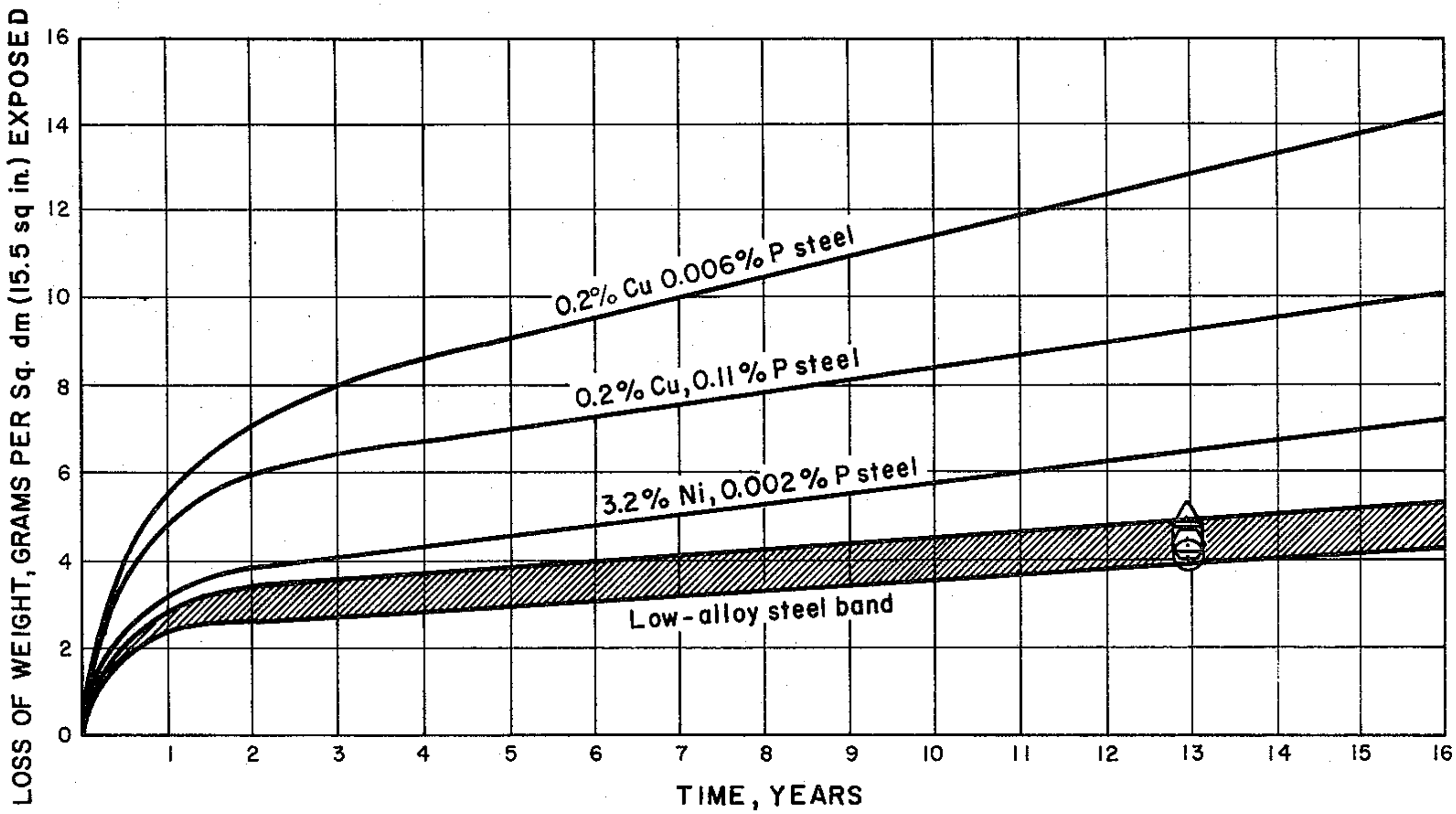
ATMOSPHERIC CORROSION OF STEELS TRANSLAB DATA POINTS SUPERIMPOSED ON A GRAPH OF AS A FUNCTION OF TIME (INDUSTRIAL AREA) FROM THOMAS AND ALDERSON

FIGURE 13

compare favorably. The average weight loss of the four specimens for the same surface area as that of the Thomas and Alderson specimens is 14.0 grams and the projection of their curve to 13 years comes out at 15.5 grams. The industrial location (Los Angeles), however, did not compare as favorably. The average weight loss of the four specimens is less than 4 grams at 13 years versus 6 grams at 5 years for the Thomas and Alderson specimens. A graph (Figure 14) from the metals handbook by C. Larrabee also shows that the weight loss of the carbon steel specimens in Los Angeles compares to the weight loss of low alloy steel in an industrial atmosphere.(3)

5.7.2 Corrosion Product Analysis

The loose corrosion products that were retained from the specimens were analyzed for sulphur content and chlorine content. These results are presented in Table F, Appendix A. The sulfur contents of the specimens were highest in Los Angeles as expected but followed closely by the Sacramento specimens. The percentages were averaged and found to be .90, .80, and .19 for Los Angeles, Sacramento, and Point Reyes, respectively. The highest chlorine content was found to be in the Los Angeles specimens. These percentages were averaged to be .55, .19, and .05 for Los Angeles, Point Reyes, and Sacramento, respectively. As it turns out, Los Angeles has the highest clorine and sulfur contents but Point Reyes has by far the highest weight loss. This can be explained by the time of wetness factor which has a significant effect on the corrosion process.(2,4) Also, the combination of high sulfur and chlorine in the absence of excess moisture may have allowed the steels to form protective coatings of corrosion



△ BUTT WELDED PLATE

⊡ MECHANICALLY ATTACHED ANGLES

⬡ ALL WELDED SPACED ANGLE

⊙ INTERMITTANTLY WELDED BUTTED ANGLES

TRANSLAB DATA POINTS SUPERIMPOSED ON A GRAPH OF ATMOSPHERIC CORROSION OF STEELS AS A FUNCTION OF TIME (INDUSTRIAL ATMOSPHERE) FROM C. LARRABEE, CORROSION HANDBOOK

FIGURE 14

products. Another possibility is that the chlorides in the Point Reyes specimens may not have been tied up in insoluble compounds and subsequently were washed away with the rains. Another factor in the high corrosiveness of the Point Reyes site is the fact that the area has the highest incidence of fog of any area in the State.(2)

5.7.3 Localized Corrosion

Localized pitting and severe corrosion was limited to the Point Reyes specimens. As mentioned earlier, the most extreme case was that of the low carbon nut used on the 4112 specimen. Sixty percent of the nut by weight was corroded away and the angle surface beneath the nut was dished out so that the corroded angle thickness was reduced 0.053 inch. This is about 22% of the weathered angle thickness. The dished out area was semicircular and ranged from 0.30 inch to 0.40 inch wide. Photographs of this specimen may be seen in Appendix B, Figures 15a and b.

The angles on specimen 3552 had two large deep pits as can be seen in the photographs of this specimen in Appendix B, Figures 16a and b. The depths of the two pits were 0.061 and 0.054 inch which is approximately 25% and 22% of the corroded angle thickness. (Original angle thicknesses were not measured. Percentages are of weathered thicknesses.) Specimen 2552 had a very high weight loss and it can be seen in the photograph in Appendix B, Figures 17a and b, that the two plates are spread about 3/16" and the tops of the angles are preferentially corroded on one side. Approximately 3/16" of the vertical height of the angles is corroded away on one side. The faces of the angles are deeply pitted to 30% of thickness. Specimen 2232 (not shown) has one large deep pit close to one corner. This pit is approximately 0.075 inch deep. Specimens 2443 and 2442 (not shown) have no localized deep pitting but the corrosion products between the butted angles has spread the angles and broken the welds. The rougher weathered surfaces were generally more deeply pitted than the finer textured surfaces.

5.7.4 Faying Surfaces

The faying surfaces of the mechanically attached angles specimens from Sacramento and Los Angeles were free of pitting. The faying surfaces of all but one of the mechanically attached Point Reyes specimens were significantly pitted. The one specimen free of pitting was 4212 (not shown). Pictures of the pitted surfaces of selected specimens are included in Appendix B, Figures 18a, b and c.

6. REFERENCES

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4. Guttman, Herbert, and Sereda, P. J., Measurement of Atmospheric Factors Affecting the Corrosion of Metals, Metal Corrosion in the Atmosphere, ASTM STP435.

5. Larrabee, C., The Corrosion Handbook, John Wiley & Sons, Inc.

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9. Standard Recommended Practice for Preparing, Cleaning, and Evaluating Corrosion Test Specimens, ANSI/ASTM G-1-72 (Reapproved 1979).

10. C. P. Larabee and S. K. Coburn, "The Atmospheric Corrosion of Steels as Influenced by Changes in Chemical Composition," Metallic Corrosion First International Congress on Corrosion, Butterworth's, London, 1962.

APPENDIX A

HARDWARE AND TORQUES USED ON MECHANICALLY ATTACHED ANGLES

SPECIMEN I. D.	PRODUCER OR SOURCE	STEEL GRADE	HARDWARE SPECIFICATION	BOLT DIAMETER INCHES	TORQUE FT-LBS.
4111 4112 4113	U.S. Steel	Cor-ten A (A242)	A-325	5/8	230
4211 4212 4213	U.S. Steel	Cor-ten B (A242)	A-325	5/8	230
4311 4312 4313	U.S. Steel	T-1 (514 GR.F)	A-325	5/8	230
4441 4442 4443	Bethlehem Steel	Mayari R (A242)	A-325	3/4	340
4551 4552 4553	CHC	Carbon Steel (A7)	A-325	3/4	340
4121 4122 4123	Kaiser Steel	Kaisaloy 50CR (A588 GR.H)	Hi Strength Weathering & UNS Medium Carbon Heat Treated	3/4	340
4131 4132 4133	Armco Steel	Hi Strength A (A242)	Hi Strength A (A325)	5/8	230
4231 4232 4233	Armco Steel	SSS100 (A517 GR.E)	Hi Strength A (A325)	5/8	230
4331 4332 4333	Armco Steel	SSS100 (A517 GR.D)	Hi Strength A (A325)	5/8	230

Table A

TABLE B

ASTM DESIGNATIONS OF THE SPECIMEN COMPONENTS
AND PHYSICAL AND CHEMICAL DATA*

PRODUCER	PRODUCT NAME	TYPE STEEL	ORIGINAL ASTM DESIG.	CURRENT ASTM DESIG.	MIN. YLD. KSI	MIN. ULT. KSI	C	Mn	P	S	Si	Cu	Ni	Cr	Mo	V	Ti	B
USS	Cor-Ten A	Plate	A242	A242 Type 1	50	70	0.09	0.42	0.13	0.019	0.57	0.36	0.48	1.0				
USS	Cor-Ten A	Angle	A242	A242 Type 1	50	70	0.09	0.35	0.11	0.018	0.35	0.32	0.40	1.06				
USS	Cor-Ten B	Plate	A242	A588 Gr.B	50	70	0.16	1.13	0.028	0.036	0.23	0.32	0.028	0.60		0.056		
USS	Cor-Ten B	Angle	A242	A588 Gr.B	50	70	0.20	1.20	0.021	0.021	0.20	0.36		0.46		0.045		
USS	T-1	Plate	A514 Gr.F	A514 Gr.F	100	115 to 135	0.15	0.86	0.015	0.019	0.27	0.30	0.93	0.55	0.41	0.04	0.005	0.0028
USS	T-1	Angle	A514 Gr.F	A514 Gr.F	100	115 to 135	0.16	0.86	0.021	0.033	0.26	0.30	0.86	0.54	0.43	0.05	0.005	0.0032
Armco	Hi Strength A	Plate	A242	A588 Gr.G	50	70	0.10	0.50	0.010	0.018	0.34	0.34	0.67	0.64			0.050	
Armco	Hi Strength A	Angle	A242	A588 Gr.G	50	70	0.13	0.50	0.011	0.022	0.35	0.34	0.73	0.54	0.10		0.058	
Armco	SSS-100	Plate	A514 Gr.E	A514 Gr.E	100	115 to 135	0.16	0.57	0.014	0.018	0.33	0.26	0.12	1.90	0.45			
Armco	SSS-100	Angle	A514 Gr.E	A514 Gr.E	100	115 to 135	0.16	0.57	0.014	0.018	0.33	0.26	0.12	1.90	0.45			
Armco	SSS-100A	Plate	A514 Gr.D	A514 Gr.D	100	115 to 135	0.15	0.56	0.010	0.014	0.27	0.24	0.09	0.91	0.20			
Armco	SSS-100A	Angle	A514 Gr.D	A514 Gr.D	100	115 to 135	0.15	0.56	0.010	0.014	0.27	0.24	0.09	0.91	0.20			

*Physicals are ASTM requirements - Chemistries are from analysis

TABLE B (Continued)

ASTM DESIGNATIONS OF THE SPECIMEN COMPONENTS
AND PHYSICAL AND CHEMICAL DATA*

PRODUCER	PRODUCT NAME	TYPE STEEL	ORIGINAL ASTM DESIG.	CURRENT ASTM DESIG.	MIN. YLD. KSI	MIN. ULT. KSI	C	Mn	P	S	Si	Cu	Ni	Cr	Mo	V	Ti	B
Armco	SSS-100A	Hi Strength Bolt	A325	A325	88	120	0.10	0.56	0.010	0.013		0.33	0.63	0.56	0.07		0.04	
Bethlehem	Mayari R	Plate	A242	A242 Type 1	50	70	0.08	0.75	0.09	0.018	0.33	0.30	0.73	0.60				
Bethlehem	Mayari R	Angle	A242	A242 Type 1	50	70	0.11	0.89	0.06	0.027	0.35	0.29	0.64	0.61				
Kaiser	Kaisaloy 50 CR	Plate	--	A588 Gr.H	50	70	0.12	0.44	0.025	0.036	0.44	0.25	0.36	0.18	0.09	0.08	0.02	
Kaiser	Kaisaloy 50 CR	Angle	--	A588 Gr.H	50	70	0.11	0.44	0.014	0.033	0.41	0.24	0.35	0.19	0.08	0.08	0.02	
CHC	A-7	Plate	A-7	A283 Gr.D	33	60 to 72	0.13	0.50	0.017	0.023	0.01	0.08						
CHC	A-7	Angle	A-7	A283 Gr.D	33	60 to 75	0.24	0.61	0.011	0.034	0.06	0.02						
CHC	A-7	Plate	A-7	A283 Gr.D	33	60 to 72	0.21	0.88	0.009	0.24	0.05	0.04						
CHC	A-7	Angle	A-7	A283 Gr.D	33	60 to 75	0.19	0.48	0.006	0.034	0.17	0.51						

*Physicals are ASTM requirements - Chemistries are from analysis

Table C Page 1
Weight Loss and Measurement Data
by Producer and Propietary Name

I. D.	TYPE STEEL	PRODUCER	LOCATION OF EXPOSURE	ORIGINAL WEIGHT	WEIGHT + CORROSION PRODUCTS	WEIGHT AFTER CLEANING	WEIGHT LOSS GRAMS	TOTAL AREA dm^2	WEIGHT LOSS gm/dm^2	ORIG. AVE. PLATE THICK. INCHES	FINAL AVE. PLATE THICK. INCHES	DIFFERENCE PLATE THICK. INCHES
1111	Cor-ten A	U.S. Steel	Sac.	3170	3180	3130	40	17.55	2.28	.1893	.1860	.0033
1112	Cor-ten A	U.S. Steel	Pt. Reyes	3305	3302	3152	153	18.27	8.37	.1866	.1826	.0040
1113	Cor-ten A	U.S. Steel	L.A.	3289	3282	3216	73	18.13	4.03	.1859	.1835	.0024
1211	Cor-ten B	U.S. Steel	Sac.	12246	12255	12201	45	18.24	2.47	.7588	.7564	.0024
1212	Cor-ten B	U.S. Steel	Pt. Reyes	12841	12802	12648	193	19.05	10.13	.7587	.7538	.0049
1213	Cor-ten B	U.S. Steel	L.A.	12864	12858	12786	78	19.02	4.10	.7605	.7573	.0032
1311	T-1	U.S. Steel	Sac.	8919	8928	8876	43	18.71	2.30	.5170	.5151	.0019
1312	T-1	U.S. Steel	Pt. Reyes	9135	9135	8957	178	19.05	9.34	.5156	.5109	.0047
1313	T-1	U.S. Steel	L.A.	9300	9285	9217	83	19.41	4.28	.5144	.5116	.0028
1441	Mayari	Bethlehem Steel	Sac.	4543	4553	4499	44	18.75	2.35	.2524	.2524	.0030
1442	Mayari	Bethlehem Steel	Pt. Reyes	4376	4357	4190	186	18.61	9.99	.2487	.2415	.0072
1443	Mayari	Bethlehem Steel	L.A.	4719	4711	4638	81	19.07	4.25	.2624	.2570	.0054
1551	A-7	CHC	Sac.	4251	4253	4187	64	18.09	3.54	.2426	.2398	.0028
1552	A-7	CHC	Pt. Reyes	4368	4261	4116	252	17.81	14.15	.2539	.2448	.0091
1553	A-7	CHC	L.A.	4467	4467	4376	91	18.43	4.94	.2542	.2496	.0046

Table C Page 2
Weight Loss and Measurement Data
by Producer and Propietary Name

I. D.	TYPE STEEL	PRODUCER	LOCATION OF EXPOSURE	ORIGINAL WEIGHT	WEIGHT + CORROSION PRODUCTS	WEIGHT AFTER CLEANING	WEIGHT LOSS GRAMS	TOTAL AREA dm^2	WEIGHT LOSS gm/dm^2	ORIG. AVE. PLATE THICK. INCHES	FINAL AVE. PLATE THICK. INCHES	DIFFERENCE PLATE THICK. INCHES
2111	Cor-ten A	U.S. Steel	Sac.	2561	2578	2549	12	10.73	1.12	.1883	.1859	.0024
2112	Cor-ten A	U.S. Steel	Pt. Reyes	2620	2624	2547	73	10.99	6.64	.1850	.1824	.0026
2113	Cor-ten A	U.S. Steel	L.A.	2617	2623	2582	35	10.99	3.18	.1863	.1839	.0024
2211	Cor-ten B	U.S. Steel	Sac.	8447	8456	8422	25	12.08	2.07	.7582	.7566	.0016
2212	Cor-ten B	U.S. Steel	Pt. Reyes	8558	8534	8439	119	12.46	9.55	.7594	.7554	.0040
2213	Cor-ten B	U.S. Steel	L.A.	8509	8512	8465	44	12.53	3.51	.7592	.7561	.0031
2311	T-1	U.S. Steel	Sac.	7041	7052	7011	30	12.35	2.43	.5182	.5157	.0025
2312	T-1	U.S. Steel	Pt. Reyes	7128	7135	7046	82	12.62	6.50	.5160	.5138	.0022
2313	T-1	U.S. Steel	L.A.	7141	7131	7090	51	12.57	4.06	.5164	.5131	.0033
2441	Mayari	Bethlehem Steel	Sac.	3426	3436	3405	21	11.48	1.83	.2553	.2525	.0028
2442	Mayari	Bethlehem Steel	Pt. Reyes	3336	3331	3246	90	11.54	7.80	.2421	.2360	.0061
2443	Mayari	Bethlehem Steel	L.A.	3338	3344	3301	37	11.46	3.23	.2430	.2372	.0058
2551	A-7	CHC	Sac.	3029	3037	3000	29	10.83	2.68	.2413	.2389	.0024
2552	A-7	CHC	Pt. Reyes	3236	3123	3027	209	11.21	18.65	.2528	.2425	.0103
2553	A-7	CHC	L.A.	3190	3197	3143	47	11.13	4.22	.2529	.2478	.0051

Table C Page 3
Weight Loss and Measurement Data
by Producer and Propietary Name

I. D.	TYPE STEEL	PRODUCER	LOCATION OF EXPOSURE	ORIGINAL WEIGHT	WEIGHT + CORROSION PRODUCTS	WEIGHT AFTER CLEANING	WEIGHT LOSS GRAMS	TOTAL AREA dm^2	WEIGHT LOSS gm/dm^2	ORIG. AVE. PLATE THICK. INCHES	FINAL AVE. PLATE THICK. INCHES	DIFFERENCE PLATE THICK. INCHES
3111	Cor-ten A	U.S. Steel	Sac.	2609	2616	2586	23	11.60	1.98	.1866	.1853	.0013
3112	Cor-ten A	U.S. Steel	Pt. Reyes	2664	2655	2576	88	11.78	7.47	.1870	.1848	.0022
3113	Cor-ten A	U.S. Steel	L.A.	2667	2660	2620	47	11.89	3.95	.1881	.1861	.0020
3211	Cor-ten B	U.S. Steel	Sac.	8626	8630	8593	33	13.46	2.45	.7591	.7579	.0012
3212	Cor-ten B	U.S. Steel	Pt. Reyes	8531	8497	8398	133	13.56	9.81	.7592	.7556	.0036
3213	Cor-ten B	U.S. Steel	L.A.	8656	8652	8602	54	13.70	3.94	.7570	.7530	.0040
3311	T-1	U.S. Steel	Sac.	7017	7023	6989	28	13.33	2.10	.5183	.5169	.0014
3312	T-1	U.S. Steel	Pt. Reyes	7076	7071	6961	115	13.40	8.58	.5167	.5134	.0033
3313	T-1	U.S. Steel	L.A.	7170	7155	7109	61	13.83	4.41	.5158	.5125	.0033
3441	Mayari	Bethlehem Steel	Sac.	3576	3580	3543	33	12.79	2.58	.2562	.2534	.0028
3442	Mayari	Bethlehem Steel	Pt. Reyes	3519	3509	3420	99	12.43	7.96	.2577	.2524	.0053
3443	Mayari	Bethlehem Steel	L.A.	3654	3647	3597	57	13.09	4.35	.2560	.2503	.0057
3551	A-7	CHC	Sac.	3200	3199	3159	41	11.88	3.45	.2533	.2508	.0025
3552	A-7	CHC	Pt. Reyes	3291	3164	3060	231	12.26	18.84	.2540	.2447	.0093
3553	A-7	CHC	L.A.	3176	3179	3122	54	12.20	4.43	.2423	.2377	.0046

Table C Page 4
Weight Loss and Measurement Data
by Producer and Propietary Name

I. D.	TYPE STEEL	PRODUCER	LOCATION OF EXPOSURE	ORIGINAL WEIGHT	WEIGHT + CORROSION PRODUCTS	WEIGHT AFTER CLEANING	WEIGHT LOSS GRAMS	TOTAL AREA dm^2	WEIGHT LOSS gm/dm^2	ORIG. AVE. PLATE THICK. INCHES	FINAL AVE. PLATE THICK. INCHES	DIFFERENCE PLATE THICK. INCHES
4111	Cor-ten A	U.S. Steel	Sac.	2692	2701	2668	24	11.83	2.03	.1850	.1838	.0012
4112	Cor-ten A	U.S. Steel	Pt. Reyes	2783	2771	2668	115	12.21	9.42	.1879	.1852	.0027
4113	Cor-ten A	U.S. Steel	L.A.	2757	2752	2711	46	12.17	3.78	.1866	.1844	.0022
4211	Cor-ten B	U.S. Steel	Sac.	8424	8431	8394	30	13.35	2.25	.7569	.7554	.0015
4212	Cor-ten B	U.S. Steel	Pt. Reyes	8533	8498	8395	138	13.54	10.19	.7573	.7532	.0041
4213	Cor-ten B	U.S. Steel	L.A.	8553	8552	8501	52	13.67	3.80	.7581	.7545	.0036
4311	T-1	U.S. Steel	Sac.	7203	7209	7166	37	13.70	2.70	.5138	.5121	.0017
4312	T-1	U.S. Steel	Pt. Reyes	7298	7297	7185	113	13.97	8.09	.5134	.5103	.0031
4313	T-1	U.S. Steel	L.A.	7339	7327	7285	54	14.03	3.85	.5133	.5106	.0027
4441	Mayari	Bethlehem Steel	Sac.	3806	3815	3778	28	12.88	2.17	.2564	.2535	.0029
4442	Mayari	Bethlehem Steel	Pt. Reyes	3887	3874	3772	115	13.21	8.70	.2555	.2488	.0067
4443	Mayari	Bethlehem Steel	L.A.	3386	3376	3339	47	11.22	4.19	.2564	.2524	.0040
4551	A-7	CHC	Sac.	3569	3569	3532	37	11.97	3.09	.2530	.2507	.0023
4552	A-7	CHC	Pt. Reyes	3596	3489	3398	198	11.92	16.61	.2522	.2428	.0094
4553	A-7	CHC	L.A.	3570	3574	3515	55	12.24	4.49	.2424	.2378	.0046

Table C Page 5
Weight Loss and Measurement Data
by Producer and Propietary Name

I. D.	TYPE STEEL	PRODUCER	LOCATION OF EXPOSURE	ORIGINAL WEIGHT	WEIGHT + CORROSION PRODUCTS	WEIGHT AFTER CLEANING	WEIGHT LOSS GRAMS	TOTAL AREA dm^2	WEIGHT LOSS gm/dm^2	ORIG. AVE. PLATE THICK. INCHES	FINAL AVE. PLATE THICK. INCHES	DIFFERENCE PLATE THICK. INCHES
1121	Kaisaloy 50 CR	Kaiser Steel	Sac.	4607	4615	4550	57	18.59	3.07	.2617	.2586	.0031
1122	Kaisaloy 50 CR	Kaiser Steel	Pt. Reyes	4702	4689	4583	119	18.68	6.37	.2642	.2607	.0035
1123	Kaisaloy 50 CR	Kaiser Steel	L.A.	4613	4613	4536	77	18.34	4.20	.2630	.2582	.0048
1131	Hi Strength A	Armco	Sac.	4811	4822	4760	51	19.28	2.64	.2607	.2578	.0029
1132	Hi Strength A	Armco	Pt. Reyes	4815	4815	4671	144	19.16	7.52	.2593	.2531	.0062
1133	Hi Strength A	Armco	L.A.	5031	4929	4851	180	19.50	9.23	.2604	.2553	.0051
1231	SSS-100	Armco	Sac.	5047	5062	5008	39	19.06	2.05	*.2781	.2766	.0015
1232	SSS-100	Armco	Pt. Reyes	5117	5136	4944	173	19.00	9.10	.2787	.2722	.0065
1233	SSS-100	Armco	L.A.	5226	5132	5056	170	18.95	8.97	.2775	.2730	.0045
1331	SSS-100A	Armco	Sac.	4758	4770	4715	43	19.08	2.25	.2635	.2611	.0024
1332	SSS-100A	Armco	Pt. Reyes	4946	4954	4764	182	18.99	9.59	.2685	.2612	.0073
1333	SSS-100A	Armco	L.A.	4988	4899	4825	163	19.08	8.54	.2667	.2625	.0042

*Used average of other two plates

Table C Page 6
Weight Loss and Measurement Data
by Producer and Propietary Name

I. D.	TYPE STEEL	PRODUCER	LOCATION OF EXPOSURE	ORIGINAL WEIGHT	WEIGHT + CORROSION PRODUCTS	WEIGHT AFTER CLEANING	WEIGHT LOSS GRAMS	TOTAL AREA dm^2	WEIGHT LOSS gm/dm^2	ORIG. AVE. PLATE THICK. INCHES	FINAL AVE. PLATE THICK. INCHES	DIFFERENCE PLATE THICK. INCHES
2121	Kaisaloy 50 CR	Kaiser Steel	Sac.	3517	3530	3497	20	11.33	1.77	.2597	.2571	.0026
2122	Kaisaloy 50 CR	Kaiser Steel	Pt. Reyes	3555	3557	3482	73	11.32	6.45	.2608	.2564	.0044
2123	Kaisaloy 50 CR	Kaiser Steel	L.A.	3524	3533	3486	38	11.34	3.35	.2591	.2546	.0045
2131	Hi Strength A	Armco	Sac.	3468	3481	3450	18	11.22	1.60	.2687	.2665	.0022
2132	Hi Strength A	Armco	Pt. Reyes	3531	3542	3452	79	11.33	6.97	.2690	.2627	.0063
2133	Hi Strength A	Armco	L.A.	3557	3558	3518	39	11.37	3.43	.2713	.2661	.0052
2231	SSS-100	Armco	Sac.	3578	3594	3565	13	11.27	1.15	.2710	.2685	.0025
2232	SSS-100	Armco	Pt. Reyes	3616	3642	3549	67	11.28	5.94	.2713	.2658	.0055
2233	SSS-100	Armco	L.A.	3646	3648	3608	38	11.23	3.38	.2714	.2672	.0042
2331	SSS-100A	Armco	Sac.	3481	3495	3463	18	11.04	1.63	.2651	.2622	.0029
2332	SSS-100A	Armco	Pt. Reyes	3510	3529	3443	67	11.15	6.01	.2658	.2603	.0055
2333	SSS-100A	Armco	L.A.	3541	3536	3493	48	11.27	4.26	.2644	.2601	.0043

Table C Page 7
Weight Loss and Measurement Data
by Producer and Propietary Name

I. D.	TYPE STEEL	PRODUCER	LOCATION OF EXPOSURE	ORIGINAL WEIGHT	WEIGHT + CORROSION PRODUCTS	WEIGHT AFTER CLEANING	WEIGHT LOSS GRAMS	TOTAL AREA dm^2	WEIGHT LOSS gm/dm^2	ORIG. AVE. PLATE THICK. INCHES	FINAL AVE. PLATE THICK. INCHES	DIFFERENCE PLATE THICK. INCHES
3121	Kaisaloy 50 CR	Kaiser Steel	Sac.	3543	3547	3513	30	12.37	2.43	.2554	.2530	.0024
3122	Kaisaloy 50 CR	Kaiser Steel	Pt. Reyes	3527	3508	3429	98	12.44	7.88	.2541	.2496	.0045
3123	Kaisaloy 50 CR	Kaiser Steel	L.A.	3565	3561	3515	50	12.38	4.04	.2558	.2511	.0047
3131	Hi Strength A	Armco	Sac.	3589	3593	3559	30	12.16	2.47	.2609	.2581	.0028
3132	Hi Strength A	Armco	Pt. Reyes	3638	3632	3530	108	12.43	8.69	.2602	.2534	.0068
3133	Hi Strength A	Armco	L.A.	3662	3653	3607	55	12.42	4.43	.2624	.2574	.0050
3231	SSS-100	Armco	Sac.	3782	3790	3758	24	11.35	2.11	.2754	.2727	.0027
3232	SSS-100	Armco	Pt. Reyes	3818	3826	3721	97	12.18	7.96	.2761	.2715	.0046
3233	SSS-100	Armco	L.A.	3870	3867	3825	45	12.35	3.64	.2768	.2730	.0038
3331	SSS-100A	Armco	Sac.	3695	3702	3669	26	12.21	2.13	.2640	.2606	.0034
3332	SSS-100A	Armco	Pt. Reyes	3761	3757	3659	102	12.26	8.32	.2681	.2635	.0046
3333	SSS-100A	Armco	L.A.	3799	3791	3742	57	12.36	4.61	.2657	.2610	.0047

Table C Page 8
Weight Loss and Measurement Data
by Producer and Propietary Name

I. D.	TYPE STEEL	PRODUCER	LOCATION OF EXPOSURE	ORIGINAL WEIGHT	WEIGHT + CORROSION PRODUCTS	WEIGHT AFTER CLEANING	WEIGHT LOSS GRAMS	TOTAL AREA dm^2	WEIGHT LOSS gm/dm^2	ORIG. AVE. PLATE THICK. INCHES	FINAL AVE. PLATE THICK. INCHES	DIFFERENCE PLATE THICK. INCHES
4121	Kaisaloy 50 CR	Kaiser Steel	Sac.	3923	3929	3892	31	13.10	2.37	.2588	.2562	.0026
4122	Kaisaloy 50 CR	Kaiser Steel	Pt. Reyes	3913	3895	3795	118	12.93	9.13	.2574	.2512	.0062
4123	Kaisaloy 50 CR	Kaiser Steel	L.A.	3897	3894	3847	50	13.12	3.81	.2567	.2522	.0045
4131	Hi Strength A	Armco	Sac.	3591	3599	3564	27	12.56	2.15	.2604	.2575	.0029
4132	Hi Strength A	Armco	Pt. Reyes	3628	3632	3527	101	12.79	7.90	.2603	.2514	.0089
4133	Hi Strength A	Armco	L.A.	3660	3657	3606	54	12.80	4.22	.2615	.2567	.0048
4231	SSS-100	Armco	Sac.	3794	3804	3774	20	12.66	1.58	.2761	.2737	.0024
4232	SSS-100	Armco	Pt. Reyes	3858	3871	3770	88	12.61	6.98	.2767	.2720	.0047
4233	SSS-100	Armco	L.A.	3861	3856	3813	48	12.71	3.78	.2767	.2728	.0039
4331	SSS-100A	Armco	Sac.	3649	3656	3622	27	12.36	2.18	.2651	.2619	.0032
4332	SSS-100A	Armco	Pt. Reyes	3666	3669	3573	93	12.54	7.42	.2631	.2577	.0054
4333	SSS-100A	Armco	L.A.	*3783	3770	3726	57	12.76	4.47	.2695	.2647	.0048

*This original wt. incorrectly listed as 3883

TABLE D

COMPARATIVE CORROSION RESISTANCE OF FIVE WEATHERING AND THREE QUENCHED AND TEMPERED STEELS IN SUBURBAN INDUSTRIAL AND MARINE ENVIRONMENTS

MATERIAL	BUTT-WELDED PLATE			INTERMITTENTLY WELDED BUTTED ANGLE*1			ALL WELDED SPACED ANGLE			MECHANICALLY ATTACHED ANGLE		
	SAC.	PT. REYES	L. A.	SAC.	PT. REYES	L. A.	SAC.	PT. REYES	L. A.	SAC.	PT. REYES	L. A.
Cor-Ten A	1.55	1.69	1.23	2.39	2.81	1.33	1.74	2.52	1.12	1.52	1.76	1.19
Cor-Ten B	1.43	1.40	1.20	1.29	1.95	1.20	1.41	1.92	1.12	1.37	1.63	1.18
T-1	1.54	1.51	1.15	1.10	2.87	1.04	1.64	2.20	1.00	1.14	2.05	1.17
Mayari	1.51	1.42	1.16	1.46	2.39	1.31	1.34	2.37	1.02	1.42	1.91	1.07
Kaisaloy 50 CR	1.15	2.22	1.18	1.51	2.89	1.26	1.42	2.39	1.10	1.30	1.82	1.18
Hi Strength A	1.34	1.88	.54*2	1.68	2.68	1.23	1.40	2.17	1.00	1.44	2.10	1.06
SSS-100	1.73	1.55	.55*2	2.33	3.14	1.25	1.64	2.37	1.22	1.96	2.38	1.19
SSS-100A	1.57	1.48	.58*2	1.64	3.10	0.99	1.62	2.26	0.96	1.42	2.24	1.00
A-7	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

*1 Weight losses discounted because of unknown amount lost between butted angles.

*2 Weight loss discounted because of nonagreement with weight losses of all welded spaced angles and mechanically attached angles.

TYPE ENVIRONMENT AND SOURCE	CARBON STEEL	WEATHERING STEEL	QUENCHED AND TEMPERED STEEL
Marine Point Reyes	8.30 ± 1.18	4.39 ± 0.55	4.21 ± 0.44
Moderate Marine Larrabee & Coburn	9.71	5.37 ± 1.47	5.03
Industrial Commerce (L.A.)	2.32 ± 0.14	2.05 ± 0.11	2.08 ± 0.19
Industrial (Ave.of3) Larrabee & Coburn	5.93 ± 0.32	1.82 ± 0.22	2.02 ± 0.27
Suburban Sacramento	1.69 ± 0.12	1.19 ± 0.14	1.08 ± 0.15
Rural Larrabee & Coburn	4.17	1.37	1.84

COMPARISON WITH RESULTS BY LARRABEE & COBURN
ON A MILS PER 13 YEARS BASIS

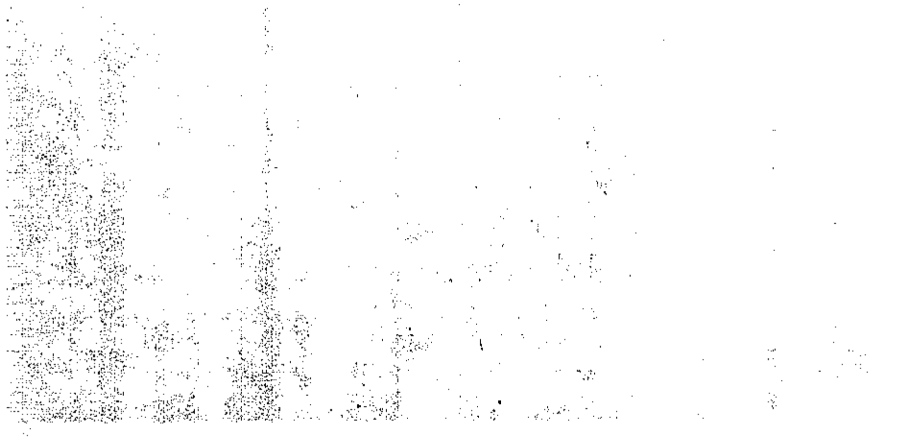
TABLE E

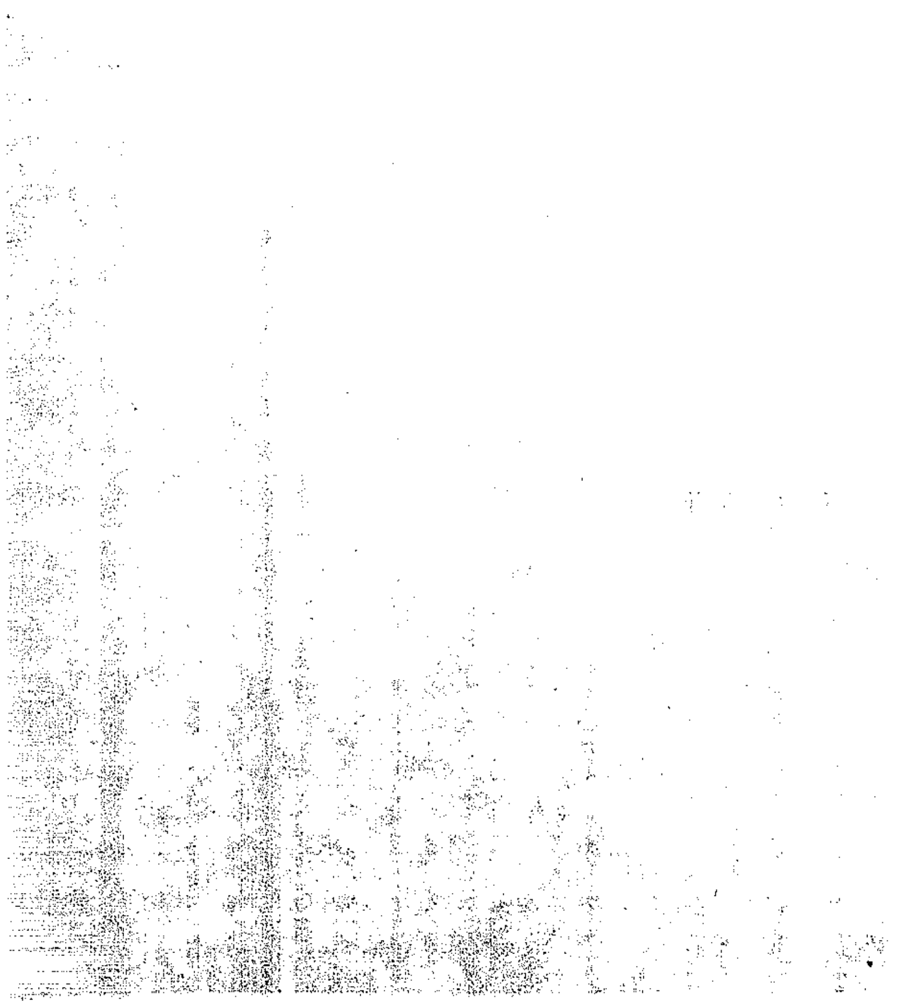
TYPE STEEL	SACRAMENTO		PT. REYES		LOS ANGELES	
	%S	%Cl	%S	%Cl	%S	%Cl
Cor-Ten A A242 Type 1	0.94	0.07	0.23	0.27	1.05	0.60
Cor-ten B A588 GR.B	0.72	0.03	0.16	0.18	0.91	0.58
T-1 A514 GR.F	0.78	0.10	0.21	0.17	0.88	0.52
Hi Strength A A588 GR.G	0.79	0.05	0.18	0.18	0.79	0.59
SSS100 A514 GR.E	0.90	0.07	0.15	0.26	0.93	0.59
SSS100A A514 GR.D	0.81	<0.01	0.22	0.15	1.03	0.55
MAYARI R A242 Type 1	0.89	0.09	0.16	0.20	0.49	0.56
KAISALOY 50CR A588 GR.H	0.75	<0.01	0.21	0.22	0.67	0.51
A-7 283 GR.D	0.65	0.04	0.06	0.10	0.81	0.43

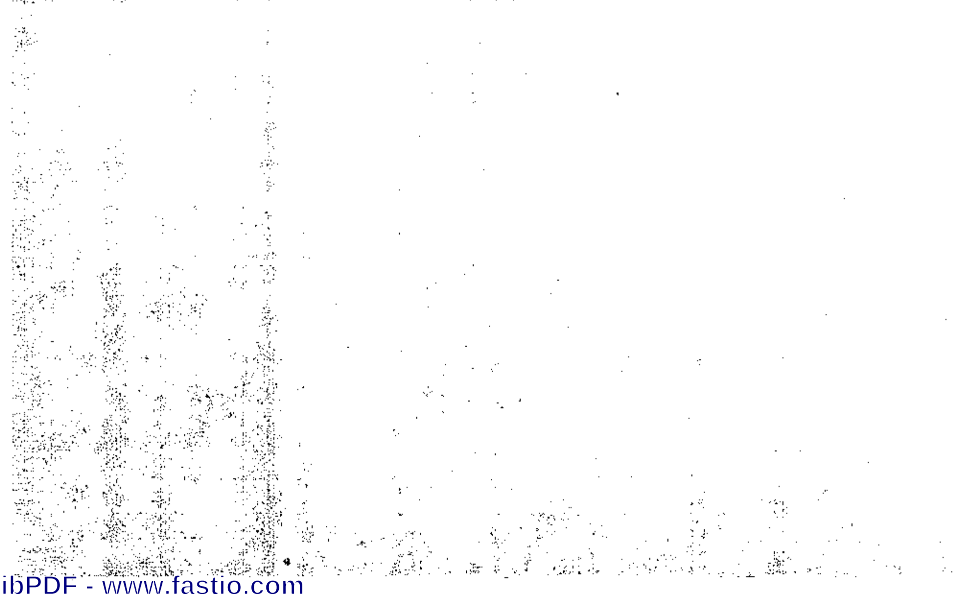
PERCENT SULFUR AND CHLORINE IN CORROSION PRODUCTS
BY LOCATION AND TYPE STEEL

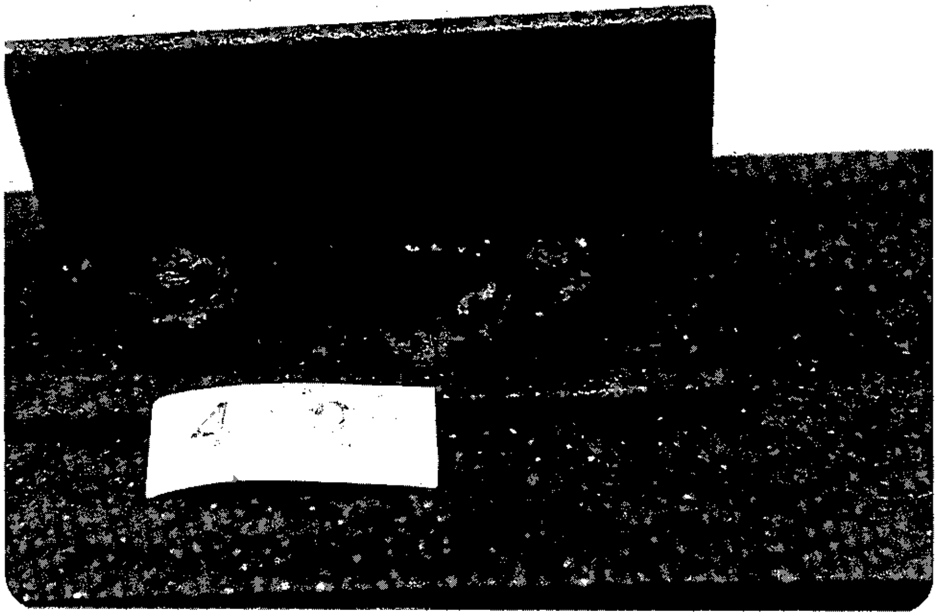
TABLE F

APPENDIX B



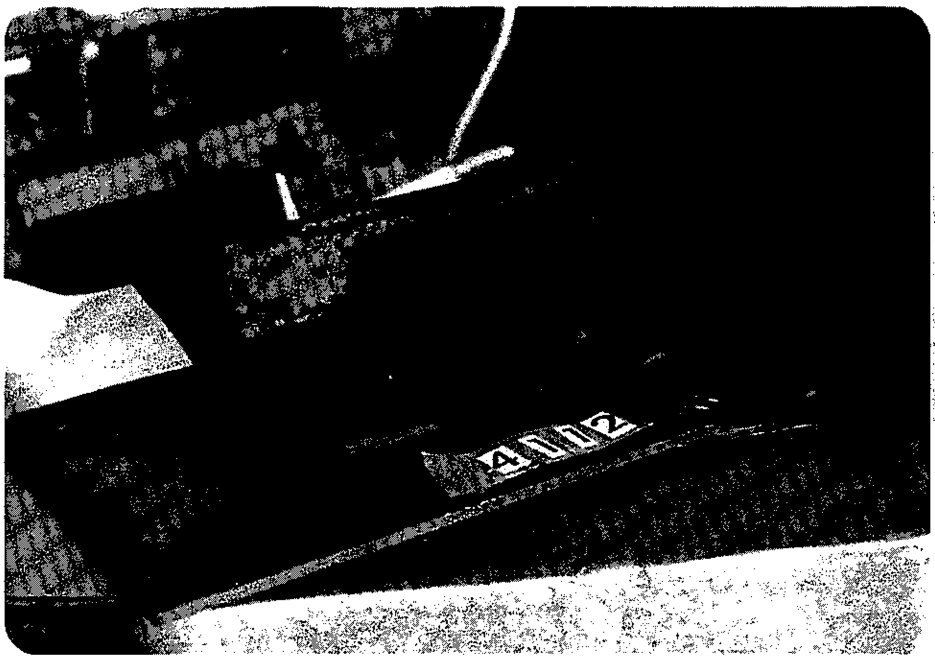






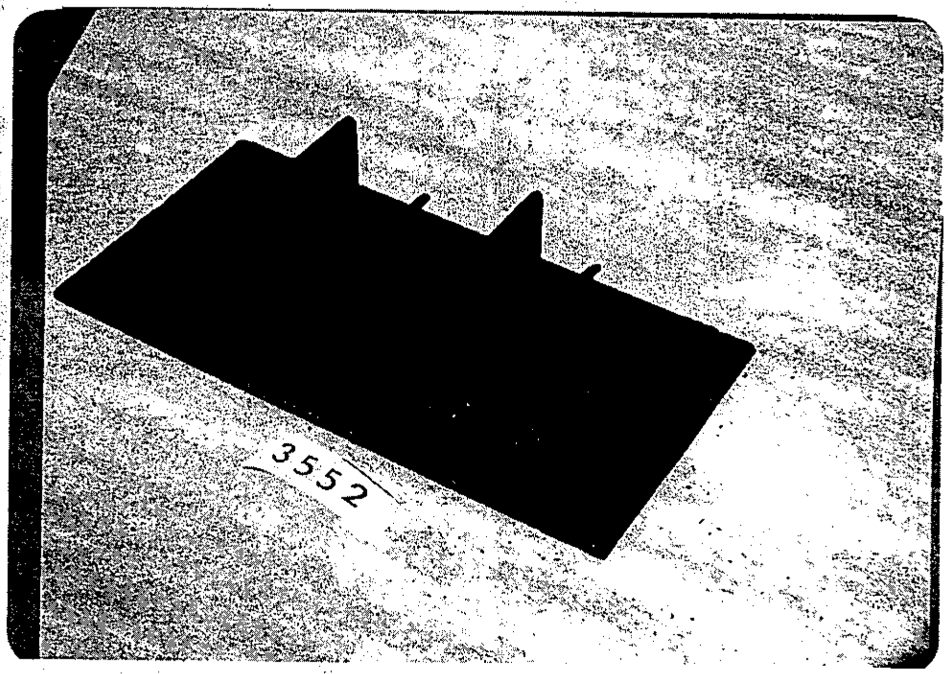
COR-TEN A STEEL SPECIMEN FROM PT REYES. LOW CARBON STEEL NUT IS 60 PERCENT CORRODED AWAY.

Figure 15a



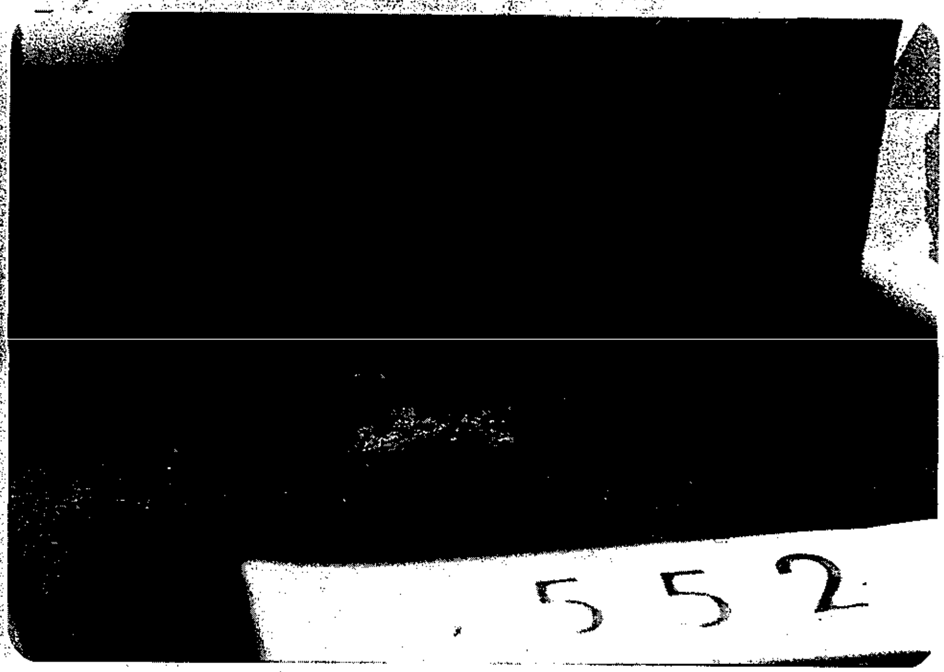
COR-TEN A STEEL SPECIMEN FROM PT REYES AFTER CORROSION PRODUCTS REMOVED. NOTE DISHED OUT AREA UNDER NUT.

Figure 15b



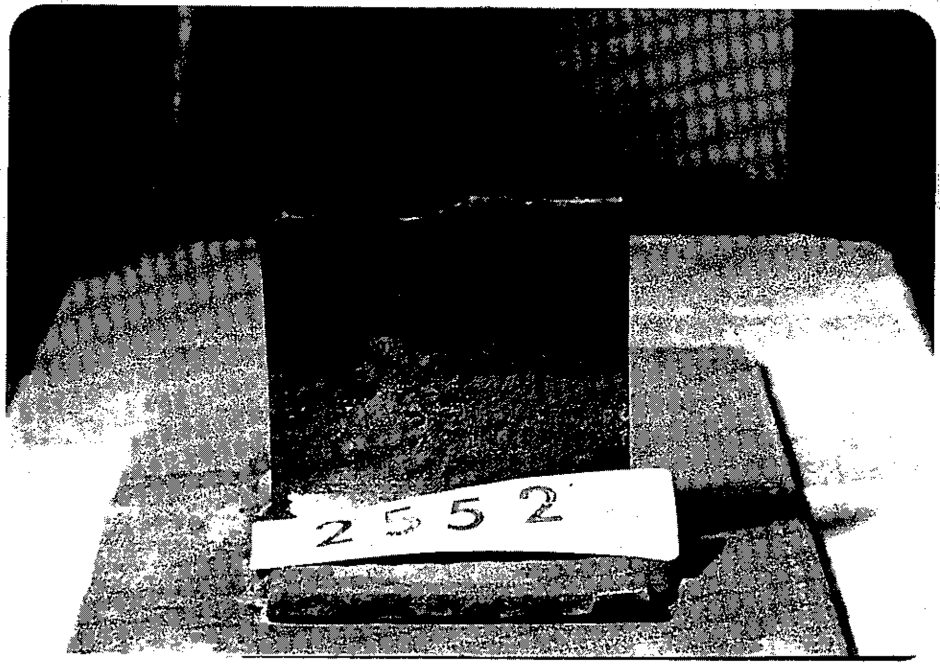
A-7 STEEL BEFORE CLEANING. ANGLE HAS 0.5 COPPER.

Figure 16a



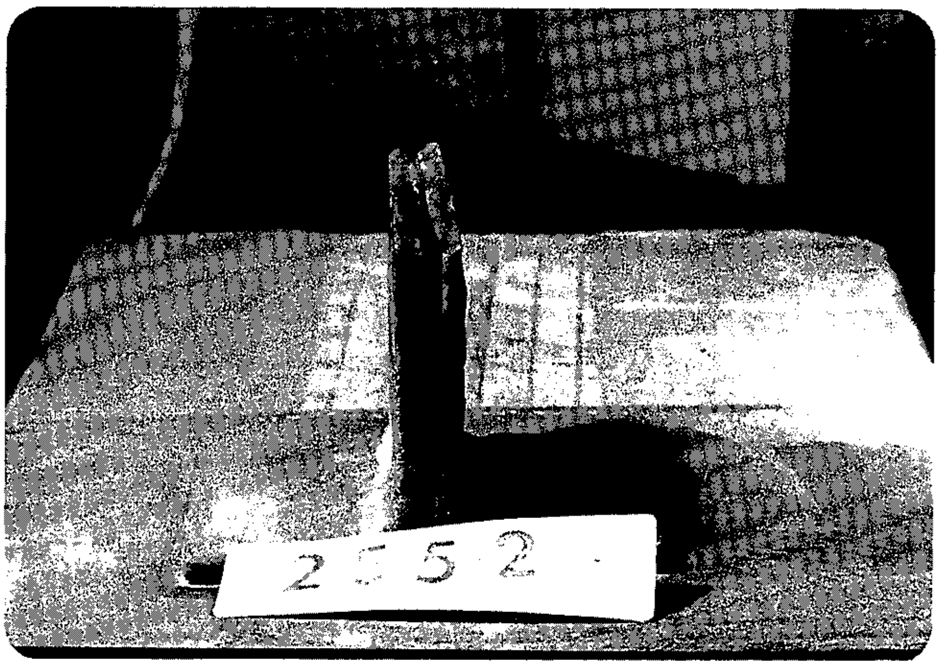
AFTER CLEANING. LOCAL CORROSION HAS CAUSED DEEP PIT.

Figure 16b



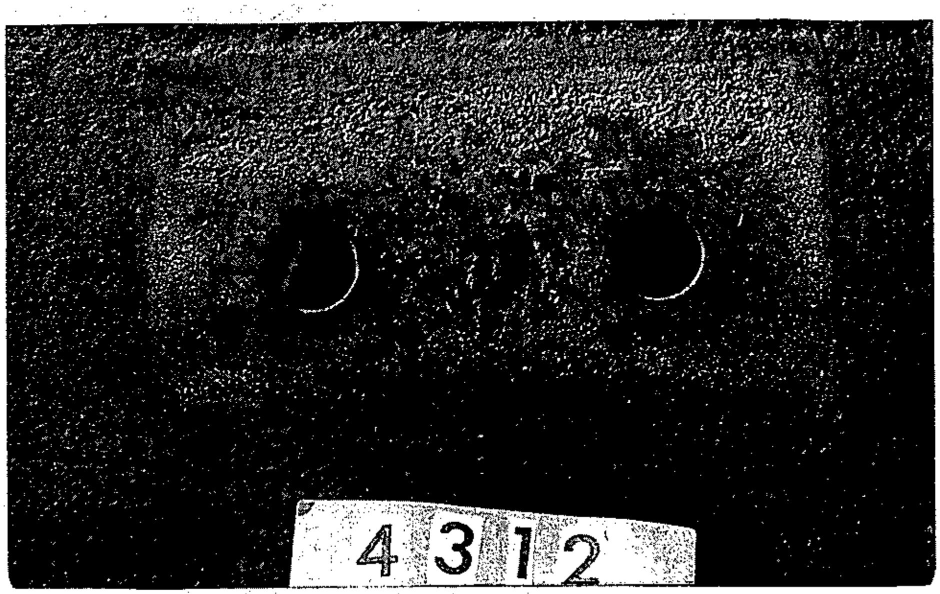
A-7 STEEL WEATHERED AT PT REYES IS SEVERELY CORRODED.
TOP LEFT HALF IS PREFERENTLY CORRODED.

Figure 17a



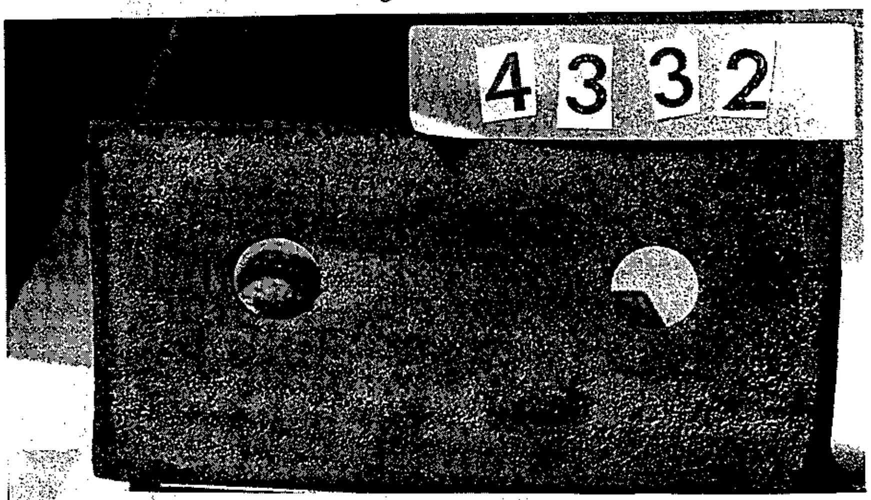
SIDE VIEW OF A-7 SPECIMEN SHOWN IN 17a.
NOTE SPREADING OF ANGLES.

Figure 17b



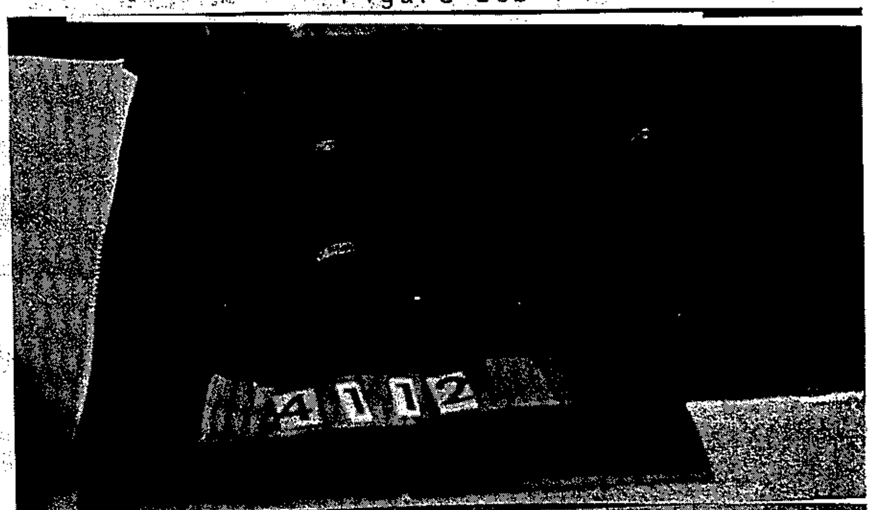
T-1 STEEL SPECIMEN FROM PT REYES.

Figure 18a



SSS 100 A STEEL SPECIMEN FROM PT REYES

Figure 18b



COR-TEN A STEEL SPECIMEN FROM PT REYES

Figure 18c